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Volume XXXV August 1940 Number 5

Economic Geology

and the

Bulletin of the Society of Economic Geologists

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MAGNETITE IN SULPHIDE ORES.

G. M. SCHWARTZ AND A. C. RONBECK.

ABSTRACT.

The literature of ore deposits indicates that magnetite occurs in a large number of sulphide deposits as an epigenetic mineral. Tabulation of 130 deposits or districts shows that the common sulphides, listed in order of number of occurrences, are: chalcopyrite, pyrite, pyrrhotite, sphalerite, galena, arsenopyrite, bornite, and chalcocite. Many lesser sulphides such as molybdenite, pentlandite, marcasite, cubanite, enargite, tetrahedrite, and covellite, also occur less commonly. Hematite (specularite) is a common associate of magnetite in these deposits.

Magnetite with sulphides occurs in deposits generally classified as of magmatic, pyrometasomatic, and hypothermal origin. It is practically absent in other types of deposits.

Tabulation of the order of formation of minerals in 52 magnetite-sulphide deposits shows that magnetite is normally the first metallic mineral to form. This suggests that, as a rule, magnetite forms only at high temperatures, possibly at a temperature which under existing conditions inhibits the formation of sulphides. In a few deposits, however, magnetite is preceded by pyrite or less commonly by other sulphides. In exceptional examples, as at Kaveltorp, Sweden, a series of sulphides are reported as preceding magnetite in a complex order of paragenesis.

Once formed, magnetite is evidently stable, as it shows only moderate evidence of replacement by later minerals.

INTRODUCTION.

THE widespread distribution of magnetite in sulphide ores is a matter of common knowledge, although forty years ago the recognition of this association in ores of hydrothermal origin was a matter of surprise. No other metallic oxide approaches the importance of magnetite in general sulphide ores, although in certain deposits other oxides are of great importance, as for example, cassiterite in tin ores. Though by no means rigidly limited to cer-

tain classes of ores, magnetite is found mainly in magmatic, pyrometasomatic, and hypothermal deposits. These deposits are usually believed to have formed at relatively high temperatures. The most closely associated sulphides therefore are pyrrhotite, pyrite, chalcopyrite, and sphalerite. Because of its normal occurrence with ore and non-metallic minerals indicative of high temperature, magnetite itself has been used as a criterion for a high temperature of formation of ores in which it is present. Lindgren [58] states that oxides such as magnetite and specularite are found in small amount in the mesothermal zone, but that the epithermal zone never contains pyrrhotite or magnetite.

It has been noted that magnetite in many sulphide ores is the earliest metallic mineral to form, though this is not invariable.

Consideration of the significance of an oxide in a dominantly sulphide ore raises many questions to which answers can scarcely be expected until the facts regarding the known occurrences of magnetite in sulphide ores have been correlated. In so far as the writers are aware, no comprehensive study of the paragenesis of magnetite in sulphide ores has been published. The general relations between magnetite and sulphides, however, have been well stated by Butler,[12b] and some of the chemical problems involved were briefly discussed. The relations described in this paper are compatible with Butler's suggestions. The present study is mainly factual. The literature has been searched for published records of important occurrences of magnetite in sulphide ores and these are summarized in the two tables. The list is no doubt incomplete, as the usual bibliographies are of little value in this sort of work. The annotated bibliography of Economic Geology is very helpful on material published in the past ten years.

A restudy of polished surfaces of magnetite-sulphide ores available in the laboratories of the University of Minnesota was also made. This study included ores from Ducktown, Tenn.; Oiseau River, Man.; Ajo, Ariz.; Sudbury and Parry Sound, Ont.; Engels, Calif.; Leadville, Colo.; Fierro, N. Mex.; Ely, Nev.; Mount Magnitaya, Russia; the Duluth gabbro, and single specimens from many districts.

Iron ores were specifically excluded from the study except in a few cases where important amounts of sulphides occur in the iron ores. Also, in so far as possible, magnetite as an original rock constituent was excluded except in concentrations in magmatic deposits. It is naturally not always possible to distinguish primary magnetite as a rock mineral from epigenetic magnetite, but most investigators have attempted to do so, and in the main their conclusions are probably reliable. Dolmage,[23b] for example, recognized both types of magnetite in the ores of Copper Mountain, British Columbia.

With the increased use of geophysical methods it seems that the magnetite content of sulphide ore is worthy of special attention. Even small amounts of magnetite produce a measurable effect on modern magnetometers, probably much more of an effect than even large amounts of pyrrhotite. Thus geophysical prospecting may be more successful in discovering sulphide bodies carrying disseminated magnetite than ores devoid of magnetite.

GENERAL STATEMENT ON ASSOCIATED MINERALS.

Magnetite is described in the literature in more or less intimate occurrence with a long list of sulphides, including particularly pyrite, chalcopyrite, pyrrhotite, sphalerite, arsenopyrite, galena, bornite, chalcocite, pentlandite, cubanite, covellite, millerite, molybdenite, marcasite, tetrahedrite, bismuthinite, bournonite, stannite. Minerals other than sulphides include native gold, tellurides, arsenides, metallic oxides, especially hematite, cassiterite, chromite, scheelite, wolframite, and many other metallic minerals. Among gangue and rock minerals magnetite is particularly closely associated with the minerals known to form in connection with hypothermal, pyrometasomatic, and magmatic deposits. Those most frequently mentioned are feldspar, pyroxene, amphiboles, micas, garnet, quartz, tourmaline, carbonates, epidote, zoisite, sericite, serpentine, ilvaite, vesuvianite, wollastonite, scapolite, fluorite, and topaz. Other minerals doubtless occur locally, but are probably not important in a general study. As a matter of fact, this is true of many of the minerals listed above and they will be referred to only incidentally.

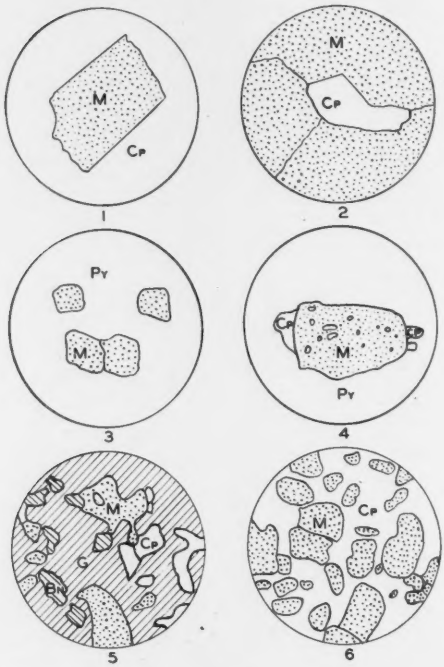

FIG. 1. Magnetite crystal surrounded by chalcopyrite. Parry Sound, Ont. × 50.

FIG. 2. Chalcopyrite surrounded by grains of magnetite. Parry Sound, Ont. × 25.

FIG. 3. Isolated grains of magnetite in pyrite. Ducktown, Tenn. × 100.

FIG. 4. Magnetite grain in a mass of pyrrhotite (Pr). Chalcopyrite (Cp) areas at contacts. Inclusions of pyrrhotite in the magnetite. Ducktown, Tenn. × 50.

FIG. 5. Irregular grains and areas of magnetite (M) with chalcopyrite (Cp), and bornite (Bn), and gangue (G). Ajo, Ariz. × 25.

FIG. 6. Rounded grains of magnetite in a matrix of chalcopyrite. Fierro, N. Mex. × 50.

General Relation of Magnetite and Sulphides.

It was recognized long ago that magnetite formed early in the sequence of ore minerals. No doubt this fact led to confusion, as it still does, between magnetite as a rock mineral and magnetite as an ore mineral. In 1916 Tolman and Rogers[97] stated that in magmatic deposits magnetite formed later than the silicates and before the sulphides; that is, it was the first in the ore mineral sequence. They believed that magnetite formed at a late magmatic stage and was replaced by sulphides.

In ores studied by the writer two relationships prevail. Where magnetite is abundant the sulphides form a matrix to euhedral or subhedral grains of magnetite (Fig. 6). Isolated subhedral or anhedral grains in sulphides commonly show evidence of attack by the sulphides (Fig. 3). In these examples the magnetite appears to have formed earlier than the sulphides and thus bears out the generalization made by Tolman and Rogers. Detailed examination of the literature, however, shows that this relationship is by no means universal. It is therefore worth while to cite some of the detailed evidences of actual association.

The data culled from an examination of the literature are assembled in two tables. The first is simply a list of 130 districts in which magnetite occurs, and the presence or absence of the eight most important sulphides is indicated by a cross for the presence of a mineral and a blank space for its absence.

Table II is a tabulation of 52 districts on which enough detailed work has been done to indicate the order of formation of the principal ore minerals. The minerals are indicated by an abbreviation with a key given below. These tables summarize a large mass of data in a small space.

It should not be assumed that every mineral listed is in contact with or closely associated with magnetite, although it is probably true that in most cases they did occur in the same ore. It would be desirable to include only those minerals intimately associated with magnetite, but in many cases descriptions are not sufficiently detailed to permit this.

TABLE I.

District.	Minerals.								
	Chalcopyrite.	Pyrite.	Pyrrhotite.	Sphalerite.	Galena.	Arsenopyrite.	Chalcocite.	Bornite.	Others.
Ajo, Ariz. (38)	x	x		x			x	x	Hematite, molybdenite
Akkezen, Russia (67)	x	x	x					x	
Ak-tyus, Russia (100)	x	x	x	x	x	x			Several
Alamo District, Lower California (65)	x	x	x	x	x				Hematite, marcasite, etc.
Altenberg, Saxony, Germany (58)	x	x		x					Several
Alexo Mine, Ont. (97)	x		x						Pentlandite
Anyox, B. C. (112)	x	x	x	x		x			
Ashley Mine, Ont. (95)	x	x	x	x	x				
Atikokan, Ont. (45)	x	x	x						
Atlin, B. C. (14)	x	x	x						Hematite, tetrahedrite
Balmat, N. Y. (9)	x	x		x	x				Hematite, willemite
Beattie Mine, Que. (30)		x				x			
Berggieshübel, Germany (106)	x	x		x	x	x	x		Tetrahedrite
Bersbo, Sweden (57)	x	x	x	x					
Bingham, Utah (57)	x	x							
Bisbee, Ariz. (8)	x	x		x	x			x	Hematite
Boliden, Sweden (70)	x	x	x	x	x	x			
Boundary District, B. C. (52)	x	x		x	x	x			Hematite, marcasite, molybdenite
Brittania, B. C. (112)	x	x	x	x	x			x	Hematite, tetrahedrite
Broken Hill, Australia (92)	x	x	x	x	x	x	x		Cubanite
Christmas District, Ariz. (112)	x	x							
Clifton-Morenci, Ariz. (54)	x	x		x					Hematite, molybdenite
Carroll County, Md. (71)	x			x			x	x	
Cobar, Australia (2)	x	x	x	x	x				Marcasite
Coeur d'Alene, Idaho (76)		x		x	x				
Conception del Oro, Mexico (112)	x	x	x	x	x				Hematite
Copper King Mining District, Nev. (113)	x	x							Pentlandite
Copper Mountain, B. C. (23b)	x	x		x	x		x	x	Hematite, covellite
Cornwall, Pa. (89)	x	x							
Cranberry Iron Mine, N. C. (78)	x	x	x	x					Molybdenite
Cranbrook, B. C. (80)	x	x	x	x	x	x			Cassiterite
Dahlonega, Ga. (40)	x	x	x	x	x	x			
Deadwood, B. C. (112)	x	x							
Deer Isle, Maine (29)	x	x		x	x				
Del Norte, Calif. (3)	x		x						
Dillsburg, York County, Pa. (43)		x							
Dobrogea, Roumania (11)	x	x						x	
Ducktown, Tenn. (32, 78)	x	x	x	x	x				Marcasite
East Kootenay, B. C. (79)	x	x	x	x	x				
Ehrenfriedendorf, Germany (34)	x	x	x	x		x			
Ely, Nev. (90)	x	x	x	x					Specularite
Engels Mine, Calif. (24)	x				x		x	x	Enargite, tetrahedrite
Erteli Mine, Norway (7)	x	x	x						Pentlandite
Erzgebirge, Germany (86)	x	x		x	x	x			

TABLE I—*Continued.*

District.	Minerals.								
	Chalcopyrite.	Pyrite.	Pyrrhotite.	Sphalerite.	Galena.	Arsenopyrite.	Chalcocite.	Bornite.	Others.
Falun, Sweden (87)	x	x	x						
Fierro, N. Mex. (81)	x	x	x	x					Cubanite
Flaad Mine, Norway (15)	x	x	x						Pentlandite
Flin Flon Mine, Man. (10)	x	x	x	x	x	x			Cubanite, tetrahedrite
Fontana, N. C. (78)	x	x	x	x	x				
Franklin Mine, B. C. (25)	x	x		x	x				
Fraser River, B. C. (48)	x	x	x						Pentlandite, hematite
Gap Mine, Lancaster Co., Pa. (15)	x	x							Pentlandite, hematite
George Mine, Stewart, B. C. (23)	x	x							
Gossan Lead, Va. (29)	x	x	x	x	x		x		
Harrison Lake District, B. C. (48)	x	x	x						
Harz Mountains, Germany (35)	x	x	x						Pentlandite
Hazelton District, B. C. (68)	x	x	x	x	x	x		x	Hematite, molybdenite
Helena District, Mont. (72)	x	x	x	x	x				
Hitachi Mine, Japan (103)	x	x	x	x	x				
Homestake Mine, S. Dak. (83)	x	x	x			x			Gold
Horne Mine, Que. (13, 75)	x	x	x	x	x				
Houston, Idaho (53)	x	x			x				Hematite
Hsianghualing, Hunan, China (64)	x	x	x	x	x	x			
Insizwa, South Africa (39)	x	x	x	x			x	x	Pentlandite, cubanite, vallerite
Kaalgoorlie, Australia (58)	x	x		x	x				Lollingite, enargite, tellurides
Kalata Deposits, Ural Mts. (28)	x	x		x					
Kaolochuw, Shansi, China (64)	x	x					x		
Kasaan, Alaska (109)	x	x							
Kaveltorp, Sweden (69)	x	x	x	x	x	x	x		Marcasite
Key West Mine, Nev. (59)	x	x		x					Pentlandite, polydmite
Kiwadi Mine, Japan (46)	x			x			x		Scheelite
Kolar, India (44)	x	x	x	x	x				
Knox County, Maine (4)	x	x	x						
Leadville, Colo. (61)	x	x		x	x				Specularite
Litchfield, Conn. (49)	x		x						Pentlandite
Little Long Lac, Ont. (96)	x	x	x	x	x	x			Tetrahedrite, berthierite
Mackay, Idaho (99)	x	x	x						Specularite
Malaya, East Indies (46)	x	x				x	x	x	Wolframite
Magdalena, N. Mex. (56)	x	x		x	x				Hematite
Marble Bay, Texada Island, B. C. (22)	x	x	x	x	x	x	x	x	Pentlandite
Meekathara, Australia (18)		x				x			
Mt. Ayliff, South Africa (85)	x	x	x	x	x		x	x	
Michipicoten, Ont. (36)	x	x	x		x				Gold
Mitate Tin Mine, Japan (105)	x	x	x	x		x			Cassiterite
Morbihan, France (53)		x	x						
Morro Velho Mine, Brazil (21)	x	x	x			x			Hematite
Morochoca, Peru (112)	x	x	x	x	x			x	Hematite, enargite, tetrahedrite
North Dundas (58)	x	x	x	x	x	x			
North Pines, Ont. (42)	x	x	x	x	x	x			

TABLE I—*Continued.*

District.	Minerals.								
	Chalcopyrite.	Pyrite.	Pyrrhotite.	Sphalerite.	Galena.	Arsenopyrite.	Chalcocite.	Bornite.	Others.
Oiseau River, Man. (82)	x	x	x	x		x			Marcasite, cubanite
Ookiep Mine, South Africa (97)	x		x					x	Hematite
Ore Knob, N. C. (78)	x	x	x	x	x		x		
Ortiz, N. Mex. (56)	x	x		x	x	x			
Ouray, Colo. (50)	x	x							
Paramint District, Calif. (62)	x	x	x						
Parry Sound, Ont. (81)	x	x	x	x				x	Cubanite
Cable Mine, Philipsburg, Mont. (31)	x	x	x			x			Hematite, gold
Pircloudan Deposits, Armenia (110)	x	x		x	x				Enargite, hematite, molybdenite
Potosi Claim, Mexico (83)	x	x	x	x	x	x			
Queensland, Australia (46)	x				x				Stibnite, wolframite, etc.
Reichenstein, Germany (30)		x	x			x			Lollingite, leucopyrite
Robertson River, B. C. (17)	x	x	x	x	x				
Roros, Norway (16)	x	x	x	x	x		x	x	
Rossland, B. C. (26)	x	x	x	x	x	x			Gersdorffite, molybdenite
Rouyn, Que. (20)	x	x	x	x					
Sachsischen, Germany (107)	x	x	x						Pentlandite
San Carlos Mts., Mexico (5)	x	x	x		x				Molybdenite, hematite
San Francisco District, Utah (12)	x	x		x	x		x		Specularite
Santa Eulalia, Mexico (74)		x	x	x	x	x			
Sedalia Mine, Colo. (55)	x	x		x	x		x		
Shasta Iron Mine, Calif. (73)	x	x							Hematite
Shebandowan, Ont. (104)	x	x	x						
Singhbum, India (27)	x	x	x						
Stobie Mine, Ont. (97)	x		x						Pentlandite
Sturgeon River District, Ont. (96)	x	x	x	x	x				Gold, hematite
Sudbury, Ont. (97)	x	x	x						Pentlandite
Tepezala District, Mexico (102)	x	x		x	x				Hematite
Texada Island, B. C. (22, 63)	x	x	x	x	x				Molybdenite, gold
Torrington, Conn. (1)	x		x			x			
Transvaal, South Africa (84)	x	x	x			x			Cubanite, pentlandite
Treadwell Mine, Alaska (88)	x	x	x	x	x	x			Molybdenite
Vancouver Island (Southern) (17)	x	x	x	x	x			x	
Verkhoyansk Range, Russia (66)	x	x		x	x	x			Gold
White Horse Rapids, N. W. Terr. (19, 94)	x	x		x	x	x		x	Hematite, molybdenite, etc.
White Knob Mine, Idaho (53)	x	x			x				Hematite
Yaguki Mine, Japan (112)	x	x	x	x	x	x			
Yale District, B. C. (47)	x	x	x	x					
Yanahara District, Japan (51)	x	x	x	x					
York Tin Mine, Alaska (93)		x		x	x				
Zeehan, Tasmania (101)	x	x	x	x	x	x			Several

TABLE II.

District.	Order of Formation of Minerals.
Alamo District, Lower California	(M Pr) H, S, Cp, G (Py Mr)
Alexo Mine, Ont.	M, Pr (Pe Cp)
Ak-tyus, Russia	Py, C, A, Mr, H, M, S, Pr, Cp, St, G
Atikokan, Ont.	M, Pr, Py, Cp
Bersbo, Sweden	M, Py, Pr, S, Cp
Carrol County, Md.	M, S, Cp, B
Clifton-Morenci, Ariz.	M (Py Cp S)
Cornwall, Pa.	M, Py, Cp
Copper King Mining District, Nev.	M, Py, Cp, Pe
Cranberry Iron Mine, N. C.	M, Py, Pr, S, Cp, Mo
Ducktown, Tenn.	M, Py, Pr (S Cp) G
East Kootenay, British Columbia	M, Ga, Sulphides
Ehrenfriedensdorf, Germany	W, C, A, M, Pr, S, Ca, Cp, Py, He
Engels, Calif.	M, Il, Cp, Bn, Cc
Erteli Mine, Norway	M, Ga, Pr, Pe, Cp
Fierro, N. Mex.	M, Py Pr, Cp, Cu, S
Flaad Mine, Norway	M, Ga, Pr, Pe, Cp
Flin Flon, Man.	M, Py (A, Pr) S (Cp, Cu) (G, Au, Te)
Fontana, N. C.	M, Py, Pr, S, Cp, Cc, Mr
Gap Mine, Penn.	M, Ga, Pe, Cp
George Mine, Stewart, B. C.	(M & H) Cp, Bo, Cc
Gossan Lead, Va.	M, Pr, S, Cp, G
Harzburg, Germany	M, Pr, Pe, Cp
Hazelton Dist., B. C.	M, Py, A, S, Tet, Ten, Cp, G
Hitachi Mine, Japan	Py, S (Cp Pr) (Py Mr) M
Horne Mine, Que.	Py, M, Pr, S, Cp, G, Au, Te or Py, Pr, M, Cp, Au, Te
Key West Mine, Nev.	M, Py, Cp, Pe, S, Po
Kaveltorp, Sweden	(Mo, Py, A) (S, Pr, Cp) Cu (S, Py, Cp) G, B, M Hydrothermal Py, Cp, Ga, M, Va, Mr, Cu
Litchfield, Conn.	M, Pr, Pe, Cp
Marble Bay, Texada Island, B. C.	(M Py) S, Mo, Cp (B, Cc) G, etc.
Michipicoten, Ont.	Py, Pr, Cp, M
Northpines Mine, Ont.	Py, M, Pr (Cp S)
Oiseau (Bird) River, Man.	M, Py, S, Pe, Cp, Cu, Mr
Ore Knob, N. C.	M, Py, Pr, S, Cp, G
Panamint District, Calif.	Py, Pr, Cp, M
Parry Sound, Ont.	M, Py, Pr, Cp, Cu, S
Robertson River, B. C.	M, Pr, Py, Cp
Roros, Norway	Py, Cp, Pr, S, M, B, Cc, G (or M earliest)
Rouyn, Que.	Py, M, Pr, S, Cp, Py
San Carlos Mts., Mexico	(Py, Cp) M
Santa Eulalia, Mexico	M, Py, A, Pr, S, G, Py
St. Eugene Mine, Cranbrook, B. C.	M, Ga, Py, Pr, S, G, etc.
Shasta County, Calif.	M (Cp, Py)
Singhbum, India	M, Py, Pr, Pe, Cp
Sudbury, Ont.	M, Py, Pr, Pe, Cp (Varied opinions)
Tepezala District, Mexico	M, Py, H, G, S, Cp
Vancouver Island (Jeune Group), B. C.	M, Pr, Py, B, Cp, Cc, Cov
Vancouver Island (Southern)	M, Pr, Py, Cp
Verkhoyansk Range, Russia	M, A, Au, Py, Cp, S, G

TABLE II—*Continued.*

District.	Order of Formation of Minerals.
White Horse Rapids, N. W. Terr.	M, H, B, Cp
Yale District, B. C.	M, Ch, Py, Pe, Pr, Cp, S
Yanahara District, Japan	M, Py, Cp (Pr Py) S

Key.

A—Arsenopyrite.	G—Galena.	Pr—Pyrrhotite.
Au—Gold.	Ga—Gangue.	Py—Pyrite.
B—Bornite.	H—Hematite.	S—Sphalerite.
Bo—Bournonite.	I—Ilmenite.	St—Stannite.
C—Cassiterite.	M—Magnetite.	Te—Telluride.
Cc—Chalcocite.	Mi—Millerite.	Tet—Tetrahedrite.
Ch—Chromite.	Mo—Molybdenite.	Ten—Tennantite.
Co—Covellite.	Mr—Marcasite.	W—Wolframite.
Cp—Chalcopyrite.	Pe—Pentlandite.	
Cu—Cubanite.	Po—Polydmite.	

Notes on Associated Sulphides.

Chalcopyrite.—The tabulations show that chalcopyrite is the most common sulphide found with magnetite. Chalcopyrite is reported in 122 of the 130 districts reviewed and it is possible that it escaped notice in some of the 8 districts from which it is not reported. Inasmuch as chalcopyrite is such a common associate of magnetite it might be expected to show a close relation with magnetite in time of formation. The tabulation of the order of formation in many deposits does not seem to bear out this inference. In most deposits pyrite and pyrrhotite are said to have formed after magnetite but before chalcopyrite.

Some of the detailed relationships reported in the literature are worthy of note. At Rossland,[26] B. C., chalcopyrite is found intermixed with massive pyrrhotite and magnetite in a monzonite country rock. At Clifton-Morenci [54] chalcopyrite is disseminated in pyroxene with magnetite, pyrite, and sphalerite. In the Ely district, Nev., the writers observed much chalcopyrite and magnetite closely intergrown, suggesting contemporaneous origin in some specimens. In other specimens chalcopyrite forms a matrix to magnetite grains. At Kasaan, Alaska,[109] large and small grains of chalcopyrite are disseminated in massive magnetite.

In the Mackay district, Idaho,[89] magnetite and chalcopyrite are said to be mutually exclusive in the various deposits.

Gilluly states that at Ajo, Ariz.,[38] there is much magnetite, chalcopyrite and bornite near the pegmatite, all of which fade away as the pegmatites are left. Magnetite is most restricted, bornite next.

In the Engels Mine, Calif.,[24] chalcopyrite and bornite occur as veinlets and replacement tongues in magnetite. In the Horne mine, Noranda, Que.[13] pyrite and chalcopyrite veinlets and stringers cut magnetite.

At Phoenix in the Boundary district,[106] B. C., chalcopyrite occurs as interspatial filling of granular aggregates of magnetite. This is the most characteristic occurrence in the specimens examined by the writer. It was observed in ores from Fierro, N. Mex.; Parry Sound, Ont.; Ely, Nev.; and elsewhere. It probably means that chalcopyrite crystallized after the grains of magnetite. In Figs. 1 to 18 various textural relations between magnetite and chalcopyrite have been sketched or photographed. Several illustrations may be found in the literature cited.

Butler[12] figures an excellent case of magnetite surrounding chalcopyrite and, as stated, magnetite probably formed later than the sulphide. A footnote refers to a similar relation in ore from Ely, Nev.

Pyrite.—The tabulations show that pyrite occurs in 115 out of the 130 deposits studied and thus ranks close to chalcopyrite in its occurrence in magnetite-bearing sulphide ores. It is generally formed early in the sequence of ore minerals, as shown by Table II. In 10 deposits out of 52, pyrite is said to have formed before magnetite and in 18 it formed immediately after magnetite. Rarely pyrite is reported as having formed at the same time as magnetite, notably at Marble Bay, Texada Island,[22] B. C. This leads one to speculate on the conditions that might cause iron oxide and iron sulphide to crystallize at the same time in epigenetic deposits. Formation of pyrite crystals on magnetite has recently been reported in experimental work.[60] It is well known that rock magnetite is commonly replaced by pyrite during hydrothermal alteration of igneous rocks.

A few of the clearer and more significant relations described in the literature may be briefly reviewed.

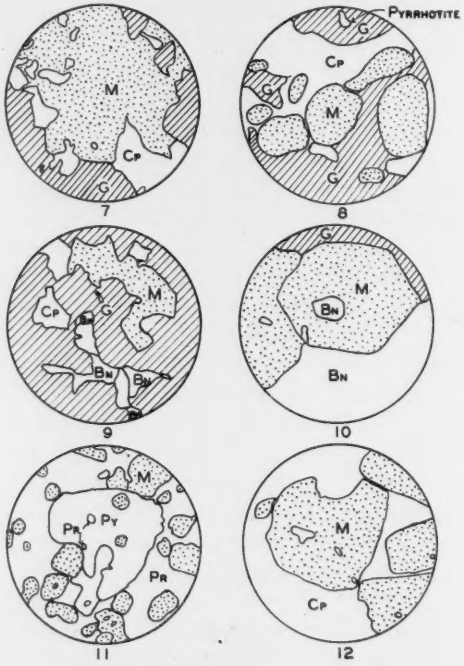

FIG. 7. Irregular area of magnetite (M) associated with and including chalcopyrite. Gangue (G). Kimberley, Nev. × 20.

FIG. 8. Rounded grains of magnetite (M) in gangue (G) and chalcopyrite. Oiseau River, Man. × 75.

FIG. 9. Very irregular area of magnetite (M) with gangue (G), chalcopyrite (Cp), and bornite (Bn). Engels Mine, Cal. × 33.

FIG. 10. Grains of magnetite (M) included in bornite (Bn) and enclosing bornite. Parry Sound, Ont. × 200.

FIG. 11. Irregular possibly corroded grain of pyrite (Py) with rounded grains of magnetite (M) in a matrix of pyrrhotite (Pr). Atikokan, Ont. × 40.

FIG. 12. Irregular grains of magnetite in a matrix of chalcopyrite. Also chalcopyrite inclusions in magnetite. Negro Creek District. × 30.

Perfect cubes of pyrite are described as surrounded by magnetite at Treadwell, Alaska.[88] At Noranda,[13] Que., magnetite and chalcopyrite cut pyrite. In other deposits of the Rouyn [13] district of Quebec magnetite formed after and to some extent replaces pyrite. At Balmat,[9] N. Y., pyrite is pseudomorphically replaced by magnetite, hematite, and sphalerite. Magnetite is usually restricted to the limits of former pyrite grains. In the Ely district,[90] Nev., pyrite and chalcopyrite are closely intergrown, but magnetite also occurs surrounding pyrite.

Magnetite also occurs enclosed in pyrite crystals at Ducktown, Tenn., and at Sudbury, Ont., pyrite and magnetite occur as inclusions in each other.

At Leadville, Colo.,[61] pyrite cements shattered limestone that had been previously in part replaced by magnetite and specularite. Pyrite fills cracks in magnetite at East Kootenay,[79] B. C. At Litchfield,[49] Conn., euhedral and subhedral magnetite is included in pyrite. At Bisbee,[8] Ariz., pyrite is described as intergrown with specularite and pyrite, and pyrite veins also cut magnetite, specularite, and earlier pyrite.

In the Comstock Lode [58] pyrite is believed to have developed from magnetite, also at Thames,[58] New Zealand. In the gold quartz veins of California magnetite was converted to ferrous carbonate.[58] Associated sulphides are pyrite and arsenopyrite. Lindgren notes that part of the pyrite was formed from ferromagnesian minerals. At Rio Tinto,[6] Spain, magnetite altered to pyrite and siderite, and Bateman believes rock magnetite has been preserved in some of the ore.

In recent experiments Lindner and Gruner [60] have shown that magnetite at 300° C. in a closed system with hydrosulphide solutions becomes covered with pyrite crystals.

Spencer [90] has noted the abundance of pyrite, magnetite, and chalcopyrite in the deposits of Ely, Nevada, where these minerals are estimated to comprise 5 to 10 per cent of a very great bulk of altered rock. Recent studies of ore from this district by the writer suggest that the sulphides are closely related to the magnetite in time of formation.

Pyrrhotite.—The relationships of magnetite and pyrrhotite were briefly discussed in a previous paper.[83] The association is a natural one inasmuch as both minerals seem to form mainly in deposits at high temperatures. In 84 of 130 deposits tabulated, pyrrhotite is recorded. In the earlier study of pyrrhotite, magnetite occurred in 35 out of 86 districts studied. In deposits with published order of formation of minerals pyrrhotite was found to precede magnetite in only 6 examples out of 52. Pyrrhotite followed immediately after magnetite in 12 of the 52 districts. In one district they were listed as contemporaneous.

Magnetite commonly occurs as anhedral to euhedral grains surrounded by a matrix of pyrrhotite (Fig. 4). Replacement of magnetite is not extensive, but the rounded form of some grains suggests such action.

The detailed notes on the relationship of pyrrhotite and magnetite reported in the earlier paper are not repeated, but a few additional examples may be cited. On South Vancouver Island [17] magnetite is more or less complementary to pyrrhotite, the two rarely occurring in the same ore, but Osborne reports pyrrhotite replacing magnetite elsewhere on the island. Ross [78] noted rounded grains of pyrrhotite in magnetite, and also magnetite cuts across a grain of pyrrhotite. Pyrrhotite fills cracks in magnetite at East Kootenay,[79] B. C.

At Ookiep, Namaqualand,[97] South Africa, pyrrhotite in part was formed by replacement of magnetite. In the deposits of the Hazelton district,[68] B. C., pyrrhotite replaces magnetite grains, but magnetite is the only mineral preceding pyrrhotite in the Juniper Creek deposits. Howe [49] refers to a few perfect pseudomorphs of pyrrhotite after magnetite in the magmatic ores of Litchfield, Conn.

Sphalerite.—Although sphalerite may not have a close genetic relation to magnetite, it is nevertheless a common associate. Sphalerite is listed in 81 of the 130 districts tabulated. Out of 50 districts where the order of paragenesis is reported, only 4 districts report sphalerite as earlier than magnetite. Rarely does sphalerite follow immediately after magnetite; in other words, sphalerite is not closely related to magnetite in time of formation.

In ores from Ely, Nev., magnetite and sphalerite are mutually included in a manner suggestive of contemporaneous formation. Sphalerite has been described in cracks in magnetite at East Kootenay,[79] B. C. Sphalerite and hematite replace magnetite at Balmat, N. Y., and finely divided magnetite occurs as a matrix in sphalerite. At Atikokan, Ont.,[45] it is reported that sphalerite has been injected in magnetite.

In the Granite mine of the Coeur d'Alene district,[76] magnetite is intergrown with sphalerite. Ransome and Calkins in 1908 stated that magnetite as a vein material with sulphides is of considerable interest.

In some ores from the Hanover (Fierro) district of N. Mex., magnetite and sphalerite are closely associated. The sphalerite is the iron-bearing variety (marmatite) of a particularly dark color so that in hand specimen it is difficult to recognize two minerals. On polishing where relief is developed, it is at once evident that grains of magnetite occur interbedded in a matrix of sphalerite.

Galena.—Lead occurs most abundantly in the deposits of the lower temperature type. Nevertheless it is common in small and occasionally in large amounts in the higher temperature deposits. Its occurrence in the latter type of deposits is emphasized by the fact that galena is found associated with magnetite in 66 out of 130 districts in Table I.

Spurr described intimate mixtures of magnetite and galena in the Helena-Frisco mine of the Georgetown quadrangle,[91] Colo.

At East Kootenay,[79] B. C., galena fills cracks in magnetite. In deposits on Printer Boy Hill, Leadville, Colo., galena and its alteration products fill interstices in rather massive magnetite.

Direct associations of magnetite and galena must be rare, as few are described in the literature reviewed.

Arsenopyrite.—It should be emphasized that the sulphides previously described are the only ones commonly associated with magnetite in sulphide ores. Many others, such as arsenopyrite, are found in a few deposits, perhaps enough to justify the belief that the occurrence is something more than accidental. Arsenopyrite occurs in 38 of 130 deposits tabulated.

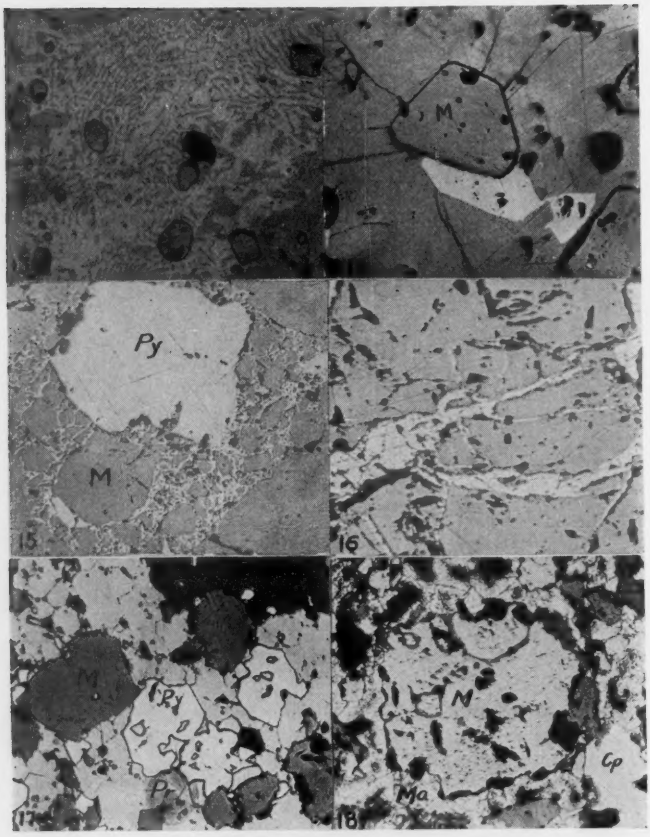

FIG. 13. Rounded grains of magnetite in a graphic intergrowth of bornite and chalcocite. Engels, Cal. × 50.

FIG. 14. Magnetite crystal (M) in bornite (gray), chalcopyrite (white), with radiating cracks occupied by covellite. Alta, Utah. × 80.

Fig. 15. Magnetite (M) with large grain of pyrite (Py) and a network of pyrrhotite (white). Mt. Magnitaya, Russia. × 65.

FIG. 16. Magnetite (gray) cut by veinlets of pyrite (white). Mt. Magnitaya, Russia. × 50.

In order of formation, arsenopyrite, like other minerals, is variable. In the Atlin district,[14] B. C., arsenopyrite is said to be the earliest mineral to form, with magnetite at the end of a complicated paragenesis. Also in the Ak-tyus district[100] of Russia, arsenopyrite is said to be earlier than magnetite, but later than pyrite. Direct associations of magnetite and arsenopyrite are rarely mentioned in the literature. Magnetite has been noted as microscopic particles in arsenopyrite-molybdenite ore at Rossland,[26] B. C., and in some specimens surrounds arsenopyrite as thin rims.

Bornite.—There are relatively few recorded occurrences of bornite in direct association with magnetite, but a few deposits have these two minerals forming the main ore. Particularly noteworthy are Engels, Calif., Parry Sound, Ont., Whitehorse District, Yukon, and Copper Mountain, B. C. In these deposits magnetite occurs as isolated grains or crystals varying to intergrown aggregates with bornite, and commonly chalcocite, as the matrix to the magnetite grains. In the deposits tabulated, 19 out of 130 include bornite.

It has been stated that bornite occurs in high temperature deposits only when iron is not abundant.[37] This seemingly does not apply to deposits carrying iron in the form of magnetite as a few deposits have magnetite and bornite as the principal minerals.

The deposits at Engels, Calif.,[24] have been much described. Grains and crystals of magnetite occur in a matrix of bornite, or bornite-chalcopyrite, or bornite-chalcocite (Fig. 13). Magnetite in places has been clearly replaced by bornite, especially in the Superior mine.[41]

Replacement veinlets of bornite cut magnetite in deposits on Vancouver Island,[17] B. C.

Bornite is intimately associated with magnetite at Ookiep,

FIG. 17. Irregular pyrite grains (Py) with pyrrhotite (Pr) and magnetite (M). Atikokan, Ont. × 165.

FIG. 18. Magnetite (M), with marcasite (Ma) and chalcopyrite (Cp). Marcasite is probably supergene. Atikokan, Ont. × 125.

South Africa, as has been described in some detail by Tolman and Rogers.[97]

Chalcocite.—Of the 130 districts tabulated only 18 contain chalcocite. In the magnetite-bearing deposits where the order of formation of the minerals has been determined, chalcocite generally formed in the late stages of mineralization, followed in places by galena and marcasite.

Grains of magnetite occur surrounded and cut by chalcocite at Clifton-Morenci, Ariz.[54] At the Engels mine, Calif., magnetite occurs as isolated grains in a pseudo-eutectic intergrowth of chalcocite and bornite (Fig. 13). It has also been described[41] as veinlets and replacement tongues in magnetite. At Kasaan, Alaska,[109] chalcocite and magnetite are intimately associated.

Pentlandite.—The tabulations show that pentlandite occurs in 16 of the 130 districts. Magnetite, at least in small amount, is somewhat characteristic of pentlandite deposits, but nickel is not widespread enough in distribution to give many associations in sulphide-magnetite ores. Pentlandite generally occurs late in the paragenetic series, and thus may not be intimately associated with magnetite, which is generally early.

At Sudbury, magnetite occurs abundantly in some ores; part is massive, but much of it occurs as euhedral to subhedral grains embedded in sulphides. Under the microscope, however, the crystals usually appear somewhat rounded and are embedded in a matrix of pyrrhotite, pentlandite, and chalcopyrite, and cracks in magnetite are filled with sulphide. Some magnetite grains contain inclusions of sulphides without indication of later origin. Tolman and Rogers[97] refer to residual magnetite in sulphides, including pentlandite.

Other Associations.—Some rare associations of magnetite are of considerable interest. Lindgren, for example, described magnetite with tellurides in the Kalgoorlie mine,[58] Australia. The association consists of gold tellurides with pyrite, chalcopyrite, sphalerite, galena, pyrargyrite, enargite, lollingite, magnetite and many nonmetallic minerals.

Umpleby found that in the Mackay[99] region of Idaho, mag-

netite in general was interstitial with respect to lime-silicate minerals and evidently formed later.

Magnetite occurs with chromite as the earliest minerals in the B. C. Nickel Mines of the Yale district.[47] Magnetite occurs as rounded grains and as small crystals in the sulphide bodies.

Zies [111] notes that chalcocite and covellite were deposited on magnetite in the fumaroles of the Valley of Ten Thousand Smokes.

Marcasite is occasionally found in magnetite-bearing sulphide ores. At Fontana, N. C., marcasite was formed at the end of the mineralization. Marcasite also replaces pyrrhotite in a few ores where magnetite is an associated mineral.

Other sulphides that have been mentioned as occurring with magnetite include molybdenite, tetrahedrite, bismuthinite, stibnite, covellite, stannite and cubanite, but direct associations are rare.

The relations of magnetite and hematite were not investigated in detail, but a few examples of the relations are particularly noteworthy. In the magnetite ore of Mount Magnitaya, Russia, martite as well as limonite are abundant in the weathered zone, but almost absent in the zone below the water table where pyrite is an important constituent.

The polished surface of a specimen from the Granby mine, B. C., has typical specularite texture with triangular interstitial areas of pyrite, chalcopyrite and gangue. The iron oxide, however, is now entirely magnetite, evidently pseudomorphous after hematite.

DISCUSSION.

No attempt was made to classify the various types of deposits tabulated, but the greater number certainly belong to the higher temperature deposits noted in the introduction. As a matter of fact, experimental evidence as well as observations in fumaroles shows that magnetite is a relatively high temperature product as has been brought out by Zies.[111] The observations in the Valley of Ten Thousand Smokes show that magnetite was deposited when temperatures were high enough to prevent condensation. Magnetite not only failed to deposit when steam condensed, but that already deposited was destroyed.

Magnetite probably occurs most commonly with sulphides in contact metamorphic (pyrometasomatic) deposits. It follows, therefore, that associations of magnetite with garnet, pyroxene, amphiboles, mica, feldspar, wollastonite, epidote, zoisite, sericite, scapolite, vesuvianite, biotite, and ilvaite are frequently mentioned in the literature.

In the deposits in the southern part of Vancouver Island, Clapp [17] gives the order of abundance of the principal minerals in the contact deposits as pyrrhotite, magnetite, chalcopyrite, pyrite.

In the deposits at Mackay,[99] Idaho, magnetite is abundant in the contact deposits, but is generally not abundant with chalcopyrite. In general magnetite is interstitial to the lime silicate minerals of the contact zone and was formed later than the silicate.

Lindgren [53] noted an intimately intergrown coarse aggregate of pyrite, chalcopyrite, sphalerite and magnetite in the Arizona Central mine at Morenci. An excellent photomicrograph (Plate X) shows an example with pyrite as the principal mineral, more or less enclosing magnetite with chalcopyrite included in both magnetite and pyrite. Sphalerite is limited to magnetite.

In the contact zone of the San Francisco district,[12] Utah, magnetite occurs around sulphide grains, also in fissures in the sulphides. The magnetite belongs to the same period of mineralization as the sulphides.

Wright [109] describes the occurrence of magnetite with chalcopyrite, pyrrhotite, and pyrite in the deposits of the Copper Mountain area in Alaska and concludes that magnetite was deposited under conditions similar to those under which the sulphides were formed.

Magnetite forms early in the series of ore minerals of most deposits. Lindgren placed magnetite early in the paragenetic series in hydrothermal ore deposits. His general sequence is as follows:

1. Various silicates, quartz, carbonates, etc.
2. Magnetite, specularite, uraninite
3. Pyrite, arsenopyrite, cobalt and nickel arsenides
4. Cassiterite, wolframite, molybdenite, etc.

That magnetite is not invariably early is shown by the data cited in Table II, and by detailed notes in a few of the papers summarized. For example, in the San Francisco district,[12] Utah, magnetite is described surrounding sulphide grains and also in fissures in sulphides.

Tolman and Rogers [97] concluded that in the magmatic sulphide ores, magnetite, as well as sulphides, formed at a late magmatic stage. Magnetite was replaced by sulphides.

Ferguson and Bateman [33] show graphically the genetic distribution and gradation of the more common minerals associated with cassiterite in tin deposits. Magnetite was formed abundantly in the pneumatolytic, and especially in the contact metamorphic stage. Sulphides are abundant in these stages and extend into the hydrothermal stage as well. Magnetite is listed in 14 of 20 of the tin areas of the world.

Some districts have a complex mineralogy and paragenesis so that no general association or sequence can be safely given for the district as a whole. The deposits of the Hazelton district, British Columbia, furnish a good example. O'Neill [68] gives the order in several deposits as follows:

Highland Boy Vein—magnetite, hematite, molybdenite, pyrite, gold, chalcopyrite and a little tetrahedrite and bornite.

Hazelton View Property—magnetite, pyrite (arsenopyrite, safflorite, löllingite), gold, molybdenite, calcite.

Cap Group—magnetite, pyrite, arsenopyrite, sphalerite, tetrahedrite, tennantite, chalcopyrite, galena.

Golden Wonder Property—magnetite, arsenopyrite, pyrite and chalcopyrite, marcasite.

Other examples of complex associations might be cited, but perhaps the general problem is sufficiently illustrated by the discussions and citations given above.

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March 14, 1940.

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PARAGENESIS IN THE HOLLINGER VEINS.

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ABSTRACT.

The ore bodies of the Hollinger Mine occur in an area of complexly folded and highly altered lava flows intruded by quartz-feldspar porphyry. The ore bodies consist of quartz veins and associated pyritized wall-rock.

The investigation is concerned with the paragenesis of the minerals of the ore bodies, particularly the relationship of gold to quartz. Results are given of a microscopic study of thin and polished sections of vein material and wall-rock, supplemented by underground study of the ore bodies.

Most of the gold occurs in a quartz-ankerite-pyrite type of ore body and was introduced later than the major period of quartz mineralization. In the veins, gold appears to be genetically related to a pale green sericite and was localized around and in inclusions of such minerals as pyrite, scheelite, arsenopyrite and ankerite. In the wall-rocks, gold is associated with pyrite but is believed to be later than it. A quartz-calcite mineralization was later than most of the gold.

Data accumulated during the investigation indicate that the veins were formed predominantly by the filling of fractures successively reopened to the waves of mineralization.

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INTRODUCTION.

THE Hollinger mine in the Porcupine District of Ontario is situated on the north-west limb of a major synclinal structure that plunges in a north-easterly direction. All the consolidated rocks are Pre-Cambrian in age. The ore-bodies occur in an area of complexly folded and highly altered Keewatin lavas that have been intruded by stocks of quartz-feldspar porphyry now largely altered to sericite schists. Albitite dikes cut the porphyries but are earlier than the veins.

The ore-bodies of the Hollinger mine and the Porcupine district in general have been studied and described by many observers.[1] As regards the Hollinger, W. C. Ringsleben [2] has described a main central ore zone that is quite regular in outline except for outliers in the northern and southern parts of the mine. It lies in a flatly curved zone having a general strike N60E and plunging at about 75° SE, thus conforming approximately to the attitude of the porphyry masses. In this region a multiplicity of quartz veins and associated mineralized rock are encountered. Some of the veins are continuous for distances of 1000 feet both laterally and vertically, but most of the ore-bodies consist of quartz networks or en echelon stringers that step over to the left, looking along the strike. Outside the main ore zone, the veins are less irregular.

Many factors pertaining to the localization of the gold still remain obscure. Perhaps the most controversial point at present

[1] Robinson, H. S.: Geology of the Pearl Lake area, Porcupine District, Ontario. ECON. GEOL., 18: 753–771, 1923. Spurr, J. E.: The gold ores of Porcupine, Ontario. Eng. and Min. Jour., 116: 633–638, 1923. Burrows, A. G.: The Porcupine gold area. Ont. Dept. of Mines Rept., 33: pt. 2, 1924. Graton, L. C., McKinstry, H. E. and others: Outstanding features of Hollinger geology. Can. Inst. Min. Met., Bull. 249, 1933. Bain, G. W.: A. I. M. E. Tech. Pub. 327: 33–38, 1930. Wall-rock mineralization along Ontario gold deposits. ECON. GEOL., 28: 705–743, 1933. Dougherty, E. Y.: Mode of formation of Porcupine quartz veins. ECON. GEOL., 20: 660–670, 1925. Mining geology of the Vipond gold mine, Porcupine district, Ontario. Can. Inst. Min. Met., Trans. 37: 260–284, 1934. Hurst, M. E.: Vein formation at Porcupine, Ontario. ECON. GEOL., 30: 103–127, 1935. Recent studies in the Porcupine area: Can. Inst. Min. Met., Bull. 291: 448–458, 1936. Charlewood, G. H.: Nature and occurrence of carbonates in veins. ECON. GEOL., 30: 503–517, 1935. Ringsleben, W. C.: Can. Min. Jour., 56: 364–370, 1935.

[2] Ringsleben, W. C., idem, pp. 369, 370, 1935.

is the relationship of gold to quartz. On this question there have been two chief schools of thought. The earlier of these [3] held that the gold occurring in the vein quartz was deposited in fractures in it, and that gold occurs only where the veins had suffered post-quartz strain. On the other hand, L. C. Graton and his associates,[4] after a detailed study of the Hollinger deposits, concluded that the greater part of the gold antedated the quartz of the veins, and that veinlets of gold now apparently in fractures in quartz are actually remnants of ones previously deposited in fractures in ankerite, which later was replaced by quartz. With this controversy chiefly in mind, the present study of Hollinger vein material was undertaken at the Miller Research Laboratory of Queen's University. Later the writer has had the opportunity of continuing the study at the mine.

The writer is especially indebted to E. L. Bruce for suggesting the work and for his constructive criticism and interest during the course of the study. To J. E. Hawley and H. W. Fairbairn, he is indebted for helpful advice. W. R. Dunbar and W. A. Jones of the Hollinger geological staff and W. C. Ringsleben formerly of the same staff contributed valuable information accumulated during their long and detailed study of the deposit. To M. E. Hurst, the writer is indebted for helpful discussion. John Knox, general manager of Hollinger, kindly consented to publication of the paper.

MINERALOGY OF THE GOLD DEPOSITS AS DETERMINED BY PRESENT STUDY.

For purposes of study the veins have been considered as consisting of two mineralogical groups: [5]

1. *Quartz-Ankerite Veins.*—These occur in the central ore zone, and all the productive veins are of this type. Ankerite occurs in these veins in varying amounts. Albite is present in most of them but is most abundant in certain veins near the margin of the quartz-ankerite zone. Tourmaline and scheelite are most abundant in veins near the Pearl Lake porphyry. Arsenopyrite, pyrite, pyrrhotite, sphalerite, chalcopyrite, galena,

[3] Burrows, A. G.: *Op. cit.*, pp. 51–54, 1924.

[4] Graton, L. C., McKinstry, H. E., and others: *Op. cit.*, pp. 13–14, 1933.

[5] A similar classification has been given by L. C. Graton et al., *op. cit.*, p. 11.

tellurides, sericite and gold occur, generally in subordinate amounts. The wall-rocks of such veins are generally highly altered and contain abundant pyrite.

2. *Quartz-Calcite Veins.*—These occur outside the productive quartz-ankerite zone but also are present within it. In all cases they are unproductive. Some of these veins contain little calcite, others consist entirely of calcite. Tourmaline, albite, axinite, common epidote, fouqueite, sericite, chlorite and gold are present, generally in small amounts. As a rule the wall-rocks of these veins are relatively fresh with no or very minor development of pyrite.

The Quartz-Ankerite Type of Vein.

Quartz and Ankerite.—The greater part of the filling of most of the veins classed in this group consists of quartz, which is generally white with a dull luster. In places it is nearly colorless and glassy, and a dark bluish-grey variety is fairly common. In places a platy structure with striations on the platy surfaces is present. Not all of the quartz is of the same age. Veinlets of white quartz cut smoky grey quartz, quartz-filled fractures cross quartz veins, and veins of a third generation, containing quartz and calcite, have been observed cutting both. Under the microscope the greater part of the quartz in the quartz-ankerite veins appears coarse grained, fine-grained quartz believed to be due to recrystallization surrounds and lies within grains of strained quartz, and veinlets of later fine grained quartz cut the coarse grained type.

The proportion of ankerite in the quartz-ankerite veins varies considerably. Some consist almost entirely of carbonate but nearly all such veins grade into those containing quartz. Ankerite commonly exhibits a columnar habit. In shape the columns approach cylinders with roughly elliptical cross-sections and occur for the most part near the walls of veins with their long directions normal to the walls. In some cases the columns are slightly folded, and, rarely, vugs occur between them. There are also variations in the composition of the carbonates some of which contain practically no iron and are, strictly speaking, dolomites. These commonly occur towards the extremities of certain veins where grains of dark grey ankerite are surrounded and veined, mainly along cleavage planes, by white dolomite. The amount

of pyrite in the wall-rocks diminishes as the proportion of dolomite to ankerite in the veins increases. Gold values likewise decrease. Apparently the veins were reopened rather late in the period of pyrite-ankerite mineralization, and the lower temperature dolomite was deposited and replaced some of the ankerite. Not all the veins containing ankerite are of the same age since some have been observed to cut others.[6] The early variety is not abundant but appears to have been one of the first minerals deposited since veinlets containing tourmaline, pyrite and quartz cut it. In a few cases S-shaped gash veins of quartz traverse a vein consisting mainly of ankerite. Fairly regular quartz veinlets commonly cut across ankerite columns normal to their long directions. Under the microscope, the quartz is seen to conform to the rhombic cleavage of the ankerite and to fill small embayments in the latter. Veinlets of quartz traverse single grains of ankerite, leaving fragments of the latter with a common orientation. Some of the quartz veinlets have fairly well-matched walls, in others the walls do not match. Quartz occurring with the columnar ankerite is also columnar, and the quartz columns are similar in shape and size to those of the adjoining ankerite. There seems clearly to have been replacement of ankerite by quartz.

Tourmaline, Scheelite and Albite.—Tourmaline is a widespread and commonly abundant constituent of the quartz-ankerite veins. In some cases the veins are composed entirely of it, but generally these grade into wider quartz-ankerite-tourmaline veins. Ladder structure is typical of many veins rich in tourmaline. In these, the main part of the vein, consisting largely of tourmaline, ankerite, quartz, pyrite and in some cases a little scheelite, is cut by cross-stringers of quartz. Ankerite, quartz and pyrite are the most common and abundant associates of tourmaline. Ankerite and quartz occur as a matrix for broken and crushed tourmaline needles and as veinlets that cut masses of tourmaline. Pyrite also occurs as veinlets that cut tourmaline. Small amounts of gold, tellurides, and galena have been noted to occur in the same way. Tourmaline-bearing veins, especially those rich in tourmaline, are

[6] Unless otherwise designated the discussion of ankerite refers to the later more abundant variety.

the most contorted of all vein types. Where they are contorted, much more regular, later quartz-ankerite veins commonly cut them at various angles.

Scheelite is not abundant but rather widespread. As a rule it is intensely fractured. In some cases the fractures are not filled and do not extend beyond the scheelite. Where more severely fractured, fragments of common orientation are separated by veinlets of quartz and ankerite and, more rarely by gold. The walls of the veinlets match, indicating no replacement of scheelite.

Albite is a widespread constituent of the veins but is abundant in only a few of them. Veins that contain albite commonly exhibit typical vein-breccia structure owing to the inclusion of angular fragments of wall-rock in a matrix of albite. Generally it is so fine grained that individual laths are recognizable with difficulty in hand specimen. Under the microscope the laths are seen to be arranged in haphazard fashion. Contacts between albite and wall-rock are sharp, and the albite becomes coarser grained towards the median part of the vein. Albite occurs most commonly with ankerite and quartz, which are present as irregularly shaped masses in albite and as veinlets cutting albite. Tongues of quartz and ankerite protrude into albite grains and some of the veinlets have unmatched walls indicating some replacement. The development of pyrite and, to a lesser degree, carbonate in the wall-rocks of veins rich in albite depends to a large extent on the presence of ankerite in the vein material. Unreplaced albite in the vein apparently acted as a barrier to solutions, preventing the development of carbonate and pyrite in the wall-rock.

Pyrite.—Pyrite occurs both in the veins and the associated wall-rocks, but as a rule it is more abundant in the wall-rocks. Generally speaking, there are two types in the walls. One variety is not related to the veins; the other variety is. The former type occurs as cubes and as nodules. Cubes, generally well-developed, occur scattered throughout the lavas, in pillow margins, in the matrix of fragmental and agglomerate rocks and with the

tuffaceous sediments that occur between some of the flows. Nodules occur only in the tuffaceous sediments and are made up of a great number of pyrite cubes in a groundmass of marcasite. It would seem that the pyrite is the result of recrystallization of marcasite formed along with the sedimentary material. Most of the pyrite associated with the veins occurs as cubes, many of which are imperfect. The crystals are rarely over 3 mm. in diameter, and where abundant most of them are less than 0.3 mm. in diameter. Under the microscope it is seen that most of the small pyrite crystals are imperfect with pitted edges and rounded corners, many of them contain small, irregular inclusions of material similar to that of the surrounding wall-rock. Most of this material consists of quartz, carbonate, and sericite.

The amount of pyrite in the wall-rock decreases, and size of individual crystals increases away from the actual vein. Where veins are closely spaced, pyrite is commonly present in all of the intervening rock owing to the overlap of the pyritized zones associated with each vein. Pyrite is more abundant in wall-rock inclusions in veins than in the adjoining main mass, obviously because the inclusions were subjected to greater amounts of mineralizing solutions. In some cases only the inclusions contain it. Development of pyrite varies in a general way with degree of carbonatization of the rock. Amount of pyrite developed in the wall-rock does not depend on the amount of quartz in the adjoining vein. The occurrence of pyrite in the wall-rock depends on the presence of ankerite in the adjoining vein, but it is impossible to say whether there is a quantitative relationship, owing to the probable replacement of ankerite by quartz.

Quartz, carbonates, sericite and chlorite are commonly associated with pyrite in the wall-rocks. Quartz most commonly occurs around pyrite crystals in fringes[7] in which the crystals of quartz occur so that their C-axes are approximately parallel to each other and normal to the face of the pyrite crystal. This produces a columnar structure in the quartz. The fringes are best developed in schistose rocks, especially in porphyry. The

[7] Bain, G. W.: *Op. cit.*, Econ. Geol., pp. 709–713. Graton, L. C., et al: *Op. cit.*, pp. 13–14. Hurst, M. E.: *Op. cit.*, Econ. Geol., p. 120.

fringes are never equally developed on all faces of a pyrite crystal but are best developed in a plane parallel to the schistosity of the enclosing rock. In some cases they are present only about this plane. The quartz of the fringes is moderately clear and not greatly strained as a rule. In some cases the quartz not only occurs as fringes around pyrite crystals but also fills fractures in them. Carbonate, sericite and chlorite also occur with quartz in the fringes.

Much of the pyrite in the wall-rocks is checked by minute and apparently empty fractures, some of which are filled with quartz or carbonate; mostly the fractures do not extend beyond the pyrite grains. It is noteworthy that the fracturing of the pyrite is most intense and, in many cases, almost entirely confined to material along the margins of veins. This is especially true where the vein material is quartz.

The pyrite that occurs in the vein material is generally much coarser grained than the variety in the wall-rock, with massive and imperfectly crystallized forms more common. Clusters of pyrite crystals in the veins have the same texture as those in the wall-rocks. They probably represent remnant material from included fragments of wall-rock. Ankerite is a common matrix for the pyrite crystals. In rare cases; pyrite crystals have been found in vugs in the veins. Quartz and ankerite fill fractures in pyrite. The walls of the veinlets match well indicating very little replacement. Pyrite does not occur alone in unaltered albite but instead is in all cases partly surrounded by fine grained carbonate.

Arsenopyrite.—Arsenopyrite occurs only in vein material. Some of it is in lath-shaped crystals that can be recognized with the naked eye, some of it is so fine grained as to appear massive. Pyrite occurs as rounded grains within arsenopyrite crystals, and irregular veinlets of pyrite traverse arsenopyrite. Veinlets of ankerite and of quartz with matched walls transect arsenopyrite, and angular fragments of arsenopyrite, which evidently are portions of a single grain, lie in a matrix of quartz.

Sericite.—Sericite occurs in most veins but is rarely abundant. Commonly it is recognizable only under the microscope. It varies

from pale green to almost white and has a silvery, almost metallic lustre in some cases. Tests for vanadium and chromium on a pale green variety associated with gold gave negative results. Sericite is generally most abundant near the margins of veins, but small amounts occur across the whole width. Under the microscope, remnants of single quartz grains are seen in a matrix of sericite. It is obvious that sericite has replaced quartz extensively.

Pyrrhotite, Sphalerite, Chalcopyrite and Galena.—Pyrrhotite is not abundant, but it is common in veins that contain considerable albite, where it occurs as irregular masses and veinlets in that mineral. It is present in the same manner in ankerite and in quartz. It also commonly forms a matrix for angular grains or lath-shaped crystals of arsenopyrite.

Sphalerite and chalcopyrite are present in small amounts, and generally occur together. Small amounts of them are disseminated in the wall-rocks, where they occur both in the main mass of the rock and in pyrite. In the veins, sphalerite and chalcopyrite are associated most commonly with ankerite and with quartz, in which they occur as irregular masses and as networks of branching veinlets with unmatched walls. Chalcopyrite occurs in sphalerite in the well known intergrowths of oriented blebs and laths. One set of parallel laths commonly intersects another and where two laths cross, there is enlargement. The sides of the laths are not always straight and regular, nor do they match perfectly. Some laths taper at the ends. In another type of intergrowth, sphalerite and chalcopyrite occur in about equal quantities in an irregular pattern. Other sections show a gradation from a zone where sphalerite predominates to one in which chalcopyrite is more abundant. On the whole, the evidence favours replacement of sphalerite by chalcopyrite rather than exsolution as the process by which the various intergrowths were developed.

Galena is less abundant than sphalerite or chalcopyrite. It occurs alone or with sphalerite or chalcopyrite in small veinlets traversing ankerite and quartz. In some cases tiny veinlets of galena transect single quartz grains. Galena also occurs as blebs

in sphalerite and chalcopyrite and with chalcopyrite in tiny veinlets in sphalerite.

Tellurides.—Tellurides are not abundant and have been found in quantity in only one place in the mine. Three varieties have been recognized: petzite, hessite and tetradymite. Of these petzite is most abundant. The three minerals commonly occur together with smoothly curved mutual boundaries. The tellurides occur most commonly with ankerite, coating cleavage faces and in minute fractures in it. With quartz they are present as tiny blebs along the boundaries of quartz grains and along minute fractures in large quartz grains. The tellurides are more commonly associated with galena than with the other sulphides.

Gold.—Gold occurs both in the wall-rocks and in the veins. In the wall-rocks the greater part is associated with pyrite. This auriferous pyrite has the same appearance as the gold-free pyrite. No gold is associated with pyrite in porphyry. Gold occurs as blebs on the surface of the pyrite cubes and enclosed entirely within them. Within the pyrite the blebs of gold are irregular to rounded and in shape and size resemble inclusions of gangue, sphalerite, or chalcopyrite. Most of the blebs do not appear to be connected with the exterior of the pyrite cubes in any way. In some cases tiny veinlets of gold traverse grains of pyrite (Fig. 5). These veinlets have well-matched walls and are evidently the filling of original fractures. This mode of occurrence tends to be most common near the veins. In this connection, detailed sampling of veins where gold is not visible to the naked eye has shown that most of the gold is concentrated in the wall-rocks immediately adjoining the veins. Pyritized wall-rock more than one foot from a vein contains very little gold. It is noteworthy that tiny barren fractures connecting blebs of gold in pyrite tend to become invisible when a degree of polish sufficient to recognize the blebs of gold is attained. Thus it would seem probable that much of the apparently unfractured auriferous pyrite actually is traversed by networks of tiny fractures which are invisible at the magnification at which the blebs of gold are seen. Hence gold in the wall-rocks is later than the pyrite in them.

In the veins, gold occurs as veinlets traversing tourmaline, scheelite, albite and pyrite and as a matrix for fragments of these minerals (Figs. 1, 2). It also occurs as blebs and veinlets in fractured arsenopyrite. Much gold is found in and near patches of ankerite, generally where that mineral is embedded in quartz. Gold is most abundant as masses of varying sizes along the contacts between ankerite and quartz (Fig. 6). Within these minerals it occurs in different patterns. In ankerite, gold occurs along cleavage planes and in veinlets with straight well-matched walls indicating fracture filling with little replacement. These veinlets decrease in number and size as the distance from the quartz increases. In contrast, gold occurring in quartz is in irregular veinlets that pinch and swell along the strike, and in many cases blebs of gold are connected by apparently empty fractures. It seems obvious that the gold was deposited in different fracture patterns in the two minerals.

Although gold occurs only in veins that contain quartz, relatively little of it is in the quartz; much of it is in ankerite or pyrite present in the quartz. In quartz, veinlets of gold follow boundaries of large quartz grains, cut through them and follow zones of recrystallized quartz around large quartz grains. Gold deposition was apparently later than much of the quartz at least. Quartz associated with gold is always intensely strained, and there has been considerable recrystallization. It is common to find early gold-bearing quartz cut by later non-auriferous quartz generally with calcite. In one case a dark grey to greyish-white quartz vein containing gold, pyrite, albite and sericite is cut by a later white quartz vein with a little calcite and very little gold. This in turn is cut by small stringers containing quartz and calcite in about equal amounts. These contain no gold. Thin section examination shows the gold to be later than the early dark grey quartz (Fig. 1). In another case a white quartz vein, with pyrite and gold evenly dispersed throughout it, is cut by a flat "ladder" vein of white quartz that contains no pyrite or gold. In still another thin section of vein material, fine grained clear quartz is columnar on a veinlet of gold occurring between two large quartz

grains. It would seem that gold was introduced in greatest amounts after the first generation of quartz, and that later quartz and quartz-calcite veins (Fig. 1) came in after the main period of gold mineralization.

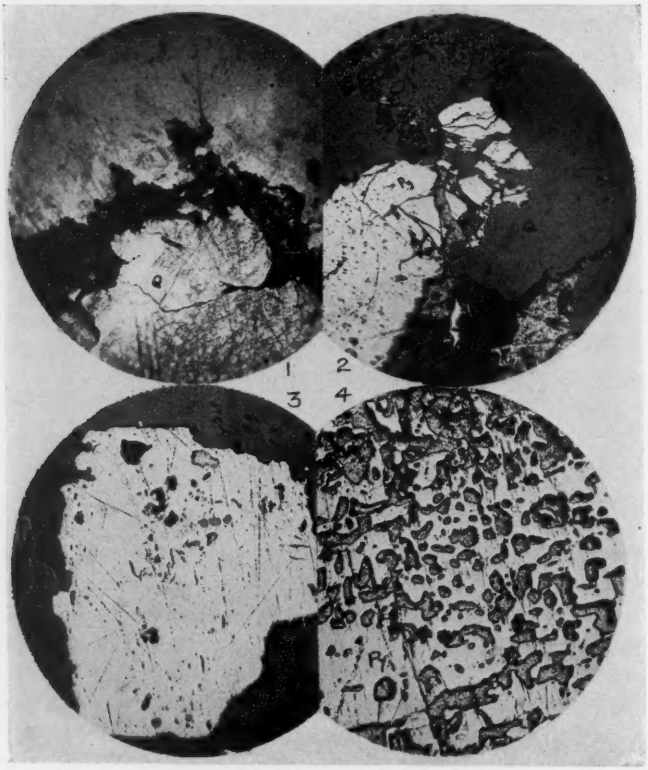


FIG. 1. Veinlet of gold (black) associated with carbonate (dark grey) and filling fracture in vein quartz (Q). One Nicol. × 15.

FIG. 2. Quartz (Q) and gold filling fractures in pyrite (Py) in the vein. × 23.

FIG. 3. Blebs of gold in pyrite in wall-rock. × 100.

FIG. 4. Gold (Au) replacing pyrite (Py) in the vein. × 100.

Pale green sericite is a particularly characteristic constituent of many high grade veins, although in most cases the gold is not actually found in the sericite. In thin section the sericite is seen to occur in veinlets that follow boundaries of grains of first-

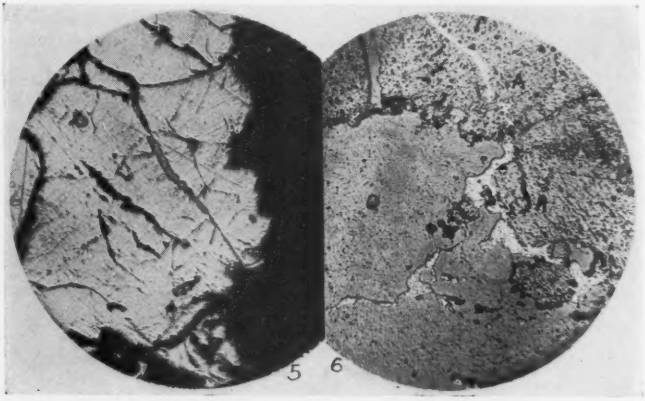


FIG. 5. Veinlet of gold in fractured pyrite in wall-rock immediately adjoining vein material (Vn). × 100.

FIG. 6. Gold occurring with quartz (Q) and ankerite (A) in the vein. Note concentration of gold between quartz and ankerite, the difference in the nature of the veinlets of gold in the ankerite and in the quartz, and the separation of the quartz veinlet in the ankerite from the main mass of quartz, apparently owing to movement along the contact between the main quartz and ankerite masses. × 23.

generation quartz. Where these veinlets encounter zones of recrystallized quartz, sericite is widely disseminated throughout it. Gold behaves in the same way, suggesting that similar physical conditions existed at the time of introduction of gold and sericite, if not even some close genetic relationship between the two.

Gold is commonly found with sphalerite, chalcopyrite, galena and tellurides. It is most commonly associated with galena and tellurides where it is found as blebs and small masses in the minerals and along their contacts with quartz. Of the tellurides, gold is most intimately and abundantly intergrown with petzite where it occurs as blebs and rods.

In summation, gold in the wall-rocks is associated most commonly with pyrite and probably all of it is later than this pyrite (Figs. 3, 4). In the veins, gold occurs with, and is later than tourmaline, arsenopyrite, pyrite, scheelite, albite, ankerite, and early quartz. It is probably genetically connected with a pale green variety of sericite. Sphalerite, chalcopyrite, galena and the tellurides are commonly intergrown with gold and, although it seems to be slightly later than these minerals, there is no conclusive proof of much difference in age.

The Quartz-Calcite Type of Vein.

Veins containing calcite and quartz as the main constituents are widely distributed in the Hollinger mine. All veins outside of the ore zone are of this type. They contain small amounts of tourmaline, axinite and fouqueite, all of which are crushed and re-cemented by quartz and calcite. Chlorite forms "ribbons" in the veins, and veinlets of it traverse axinite and are in turn cut by quartz and calcite stringers. Albite is not abundant and is cut by calcite. Pyrite is sparse and occurs more commonly in the veins than in the wall-rocks. In the wall-rocks immediately adjoining some of the quartz-calcite veins there is a bleached zone, rarely more than a foot wide, which contains mainly carbonate and pyrite. However, in many cases this pyritized zone is cut by the quartz-calcite vein and is not spatially related to it, suggesting that the carbonatization and pyritization of the wall-rocks took place before the quartz-calcite period of mineralization. The fact that the vast majority of quartz-calcite veins have no such wall-rock alteration associated with them further substantiates this conclusion.

Some veins consist only of calcite, some contain other minerals, of which quartz is the most common. In certain other veins the calcite is later than the quartz. However, quartz-calcite veins cut earlier quartz or quartz-ankerite veins. In these later veins, quartz and calcite are evenly distributed and seem to be of the same age. Thus, though calcite is younger than some quartz, it is of the same age as a later generation of quartz. Calcite or

quartz-calcite vein material is common in veins of the quartz-ankerite zone. Such veins generally occur along the margins of earlier quartz-ankerite veins or cut across them at small angles. In many cases calcite is intimately intermixed with quartz-ankerite material or occurs in erratic patches in it.

Small amounts of sphalerite and chalcopyrite occurs with the quartz-calcite veins. The sphalerite is generally lighter brown color than it is in the quartz-ankerite veins. Most veins of this type are entirely barren, but in some there are small amounts of gold and such veins generally show some pyritization of the walls.

SEQUENCE OF MINERALIZATION.

In the following discussion the terms central zone or inner zone refer, in a general way, to the main productive zone where the veins are chiefly of the pyrite-ankerite-quartz type. The outer zone is the non-productive area lying outside the central zone whose veins are of the quartz-calcite type.

In the earliest stage of mineralization, small amounts of ankerite were deposited in the central zone. Tourmaline and scheelite followed and were deposited in greatest amounts near the Pearl Lake porphyry mass. In the outer zone smaller amounts of tourmaline were deposited almost simultaneously with axinite and probably fouqueite. At this time there were fewer veins and they were smaller than at present.

The second major structural readjustment in the vein-forming process affected mainly the central zone. Pre-existing veins, composed largely of tourmaline, were folded and fractured, and many entirely new fractures were opened. At this time, deposition of albite was widespread and apparently abundant in the central zone. Deposition of pyrite in the wall-rocks of the veins began during this period. The outer zone, having been less fractured, received only small amounts of albite, but chlorite seems to have been deposited in the veins of the outer zone during this period. At the close of this period of mineralization many veins were almost their present size.

A third period of fracturing, not of sufficient intensity to

reopen all of the veins in the outermost sections of the central zone, nor any of those in the outer zone, was accompanied by the most intense mineralization of the entire vein-forming period. Large volumes of emanations deposited abundant carbonate and pyrite almost simultaneously, in the wall-rocks adjoining the veins. As the intensity of mineralization decreased, arsenopyrite and coarse-grained, massive pyrite were deposited in the veins only. The main period of deposition of ankerite in the veins accompanied, but mainly followed, the development of pyrite in the wall-rocks and veins.

During a fourth major period of fracturing, the pyrite-ankerite veins of the central zone were reopened, and in addition the fracturing extended out to the fringe of the central zone and reopened many of the albite-bearing veins that had escaped the preceding pyrite-ankerite mineralization. Then abundant quartz was introduced. Recurrence of fracturing allowed entrance to the solutions from which were deposited most of the pyrrhotite, sphalerite, chalcopyrite, galena, tellurides, sericite and gold, probably in that order. Another period of fracturing reopened some of the existing quartz veins and also formed many new openings in both the central and outer zones. Deposition of a second generation of quartz followed this fracturing. It was accompanied or closely followed by small amounts of calcite, sphalerite, chalcopyrite, sericite and very little gold. Yet another period of fracturing affected mainly an area away from the central zone. Fractures formed during it were filled with a third generation of quartz and considerable calcite. Second and third generations of quartz were probably closely related in time of introduction. Calcite deposition began with or shortly after that of second generation quartz and reached a maximum during the introduction of third generation quartz. This ended the vein mineralization.

SUMMARY AND CONCLUSIONS.

Gold was introduced later than the first period of quartz mineralization. The fact that quartz is present in all veins in which gold occurs suggests that the fracturing of the first quartz, which

allowed the entrance of the gold-bearing solutions, closely followed its deposition. The two periods of fracturing may have been closely related. Second and third generation quartz and calcite were introduced later than the deposition of most of the gold.

In the veins, the localization of gold around and in such minerals as pyrite, arsenopyrite, scheelite, ankerite, and tourmaline, in the quartz was due partly to the fact that these minerals produced a heterogeneous assemblage favorable for the formation of fractures under later stress, and partly to the fact that they exerted varying degrees of precipitating power over gold. In the wall-rocks, the same reasoning applies in favour of an introduction of gold later than that of pyrite.

Gold is believed to be genetically associated with a pale green variety of sericite. They have much the same mode of occurrence and were deposited at about the same time. Most high grade veins or sections of veins contain considerable amounts of this sericite. It is not present in barren veins.

The quartz fringes that occur around pyrite grains in the wall-rocks are believed to have been formed during the metamorphism of the rocks. This quartz was most likely derived from the rocks and was deposited in relatively open spaces formed around the pyrite grains as they rotated during rock deformation.

The evidence tends to minimize replacement of wall-rock as a process in the formation of the veins. Most of the ore bodies exhibit a definite, easily discernible fracture pattern within themselves, which has not been altered to any degree by successive periods of mineralization. Contacts between vein material and wall-rock are sharp and in the case of albite and ankerite the grain size of the minerals increases towards the median part of the vein. Ankerite is commonly columnar on the wall-rocks. In some cases there are vugs containing crystals of ankerite. The arrangement of the minerals in the veins is such that the earlier minerals are more abundant along the walls as if the veins were successively reopened along their median parts. There is evidence of some replacement of the vein minerals by each other. That of albite by

ankerite, and of ankerite by quartz are the most important. Thus, although there was some replacement among the vein minerals, there does not seem to have been any appreciable replacement of wall-rocks by the vein-forming minerals.

There is no true zoning of mineralization. In spite of the fact that the mineralization of the central ore zone is characteristically quartz-ankerite, many of these veins contain quartz-calcite material, and there are also quartz-calcite veins in this zone. In many cases the unproductive extremities of productive quartz-ankerite veins are predominantly quartz-calcite with only a little quartz-ankerite material present. Isolated areas where the mineralization is quartz-ankerite are separated by sections where the veins are of the quartz-calcite type. It seems that the distribution of these two types of mineralization was due entirely to the conditions of fracturing of the rocks at the time that the various minerals were deposited. As a result, within a relatively small area, several productive zones containing quartz-ankerite veins might occur separated by zones where the veins are of the unproductive quartz-calcite type.

HOLLINGER MINE,
TIMMINS, ONTARIO,
Feb. 16, 1940.

ORIGIN OF THE NELSONITE DIKES OF AMHERST COUNTY, VIRGINIA.

CHARLES H. MOORE, JR.[1]

ABSTRACT.

Numerous bodies of nelsonite have been found in Amherst County, in the Piedmont Province of Virginia. As these bodies consist largely of ilmenite and apatite they are of more than usual economic and scientific interest. Most of them occur as dikes intruded parallel to the foliation of hydrothermally altered Lovingston quartz-mica gneiss, but some also occur in anorthosite. The dikes are believed to be genetically related to somewhat younger hypersthene granodiorite that has invaded the gneiss, and through differentiation also has yielded the anorthosite as well as numerous pegmatites. Intrusion of the granodiorite was followed by hydrothermal solutions that altered the top of the solidified intrusive, the overlying Lovingston gneiss, and the somewhat earlier intruded nelsonite.

INTRODUCTION.

NELSONITE dikes, with their peculiar association of ilmenite, apatite, and rutile, have long been of economic and scientific interest. Although nelsonites have been recognized in Nelson County and, to a lesser extent in Amherst County, in the West-Central part of the Piedmont province of Virginia for some time, there has been no agreement as to their origin.

The rutile-ilmenite deposits were studied first by Watson and Taber,[2] who ascribed a magmatic origin to the nelsonites. Ryan [3] supported the conclusions of Watson and Taber as to origin, but extended the area in which nelsonites occur southward into Amherst County. More recently, Ross [4] has suggested a hydrothermal origin for the dikes.

[1] Published by permission of the State Geologist of Virginia.

[2] Watson, T. L. and Taber, S.: Geology of the titanium and apatite deposits. Va. Geol. Surv. Bull. 111–A, 1913.

[3] Ryan, C. W.: The ilmenite apatite deposits of West-Central Virginia. ECON. GEOL., XXVIII: 266–275, 1933.

[4] Ross, C. S.: Titanium deposits of the Roseland district. Int. Geol. Cong. Guidebook 11, Northern Virginia, 1933. Mineralization of the Virginia titanium deposits. Amer. Min., Vol. 21, No. 3, 1936.

During the summers of 1938 and 1939 the writer undertook the study of the geology of Amherst County, Virginia, and had occasion to examine the nelsonite bodies in considerable detail. He found them to be as numerous or even more numerous than in Nelson County. Data were also obtained that indicate a slightly different origin for the nelsonites from that given by either Watson and Taber, or Ross.

ROCK TYPES.

The rocks of this area are all pre-Cambrian with the possible exception of the diabase dikes, which intrude all of the others. The rocks are, in order of age, Lovingston gneiss, and its hydrothermally altered phase, anorthosite, hypersthene granodiorite, pegmatite, nelsonite, meta-pyroxenite, and diabase dikes. All of these, except the diabase, show some evidence of hydrothermal alteration and many of them show evidence of regional metamorphism.

Lovingston Gneiss.—This rock is a gneissic quartz monzonite with the gneiss bands striking approximately N. 38° E. It was given its name by Jonas [5] from typical exposures near the town of Lovingston, Nelson County, Virginia. Watson and Taber [6] called it a biotite-quartz monzonite gneiss and described it in detail. They concluded that, although the rock is of definite igneous origin, its gneissic texture is secondary and the result of dynamic regional metamorphism rather than primary flow structure. The author is, in general, in agreement with this conclusion, although there are certain structural features developed around the edges of the body that are definitely related to its intrusion. These features will be discussed in detail in a later paper for the Virginia Geological Survey. Certain other structural features developed independently of the regional metamorphism will be taken up under the later discussion of hydrothermally altered Lovingston gneiss.

Nowhere within the area studied is the Lovingston gneiss entirely fresh and unaltered. Hand specimens that appear fresh

[5] State Map of Virginia, 1928.

[6] *Op. cit.*, p. 59.

show microscope alteration. The least-altered Lovingston appears megascopically as a distinctly banded, black and white augengneiss. The black bands are primarily biotite, the phenocrysts feldspar, and the white bands feldspar and quartz. Thin sections show the rock to be composed of potash and soda-lime feldspar, biotite, quartz, muscovite, zircon, and ilmenite. Minerals determined by their relationship to be secondary are epidote, clinozoisite, sericite, calcite, and sphene. The phenocrysts are in some cases albite and in others microcline. The proportion of orthoclase to plagioclase varies from 50–50 to 25–75. The smaller feldspar grains are commonly albite-oligoclase which in some cases carries anti-perthitic microcline. The later minerals are generally associated with the bands of biotite and muscovite, the cleavage of these latter minerals no doubt providing an easier channel for the migrating solutions. Much of the albite shows cloudy areas of epidote and sericite leading to the conclusion that the few oligoclase grains preserved are the unaltered remains of the once predominant feldspar.

Throughout the area, the Lovingston gneiss contains bands of mica schist striking roughly parallel to the general trend of the structure and ranging from a few inches in width up to as much as 200 feet. These bands are here interpreted as shear zones produced by the Paleozoic deformation. However, it is thought by some workers that the schist is not the product of shearing in the gneiss but represents undigested masses of the old quartz biotite schist that the Lovingston intruded, the location of the shears being due to this preexisting zone of weakness.

Hypersthene Granodiorite.—The hypersthene granodiorite has been described by Jonas [7] and other workers from various localities where it comprises the core of the Blue Ridge mountains. In Amherst County it intrudes the Lovingston gneiss. The granodiorite is definitely younger than the Lovingston, because within the area it has not suffered the regional metamorphic effects that affected the Lovingston. There are developed in it, however, zones of mylonite, which are interpreted as shears formed at the

[7] Jonas, A. I.: Hypersthene granodiorite in Virginia. G. S. A. Bull. 46: 47–60, 1935.

same time and by the same forces that developed the schist bands in the Lovingston. It is believed that tangential stress strong enough to shear the granodiorite to a mylonite would be sufficient to form the schist bands from the Lovingston. The granodiorite everywhere displays the effect of hydrothermal alteration, thus differing from the Lovingston. In the latter rock the alteration is in some places extremely intense and in others comparatively slight.

The granodiorite is a light to dark gray, even granular to porphyritic rock. The minerals readily identified in hand specimens are abundant gray-green to pink feldspar and minor amounts of biotite, quartz, and pyroxene. In addition, bands of green epidote traverse the granodiorite, and sericite and chlorite occur as coating on slip surfaces.

The minerals identified microscopically are essentially the same as those described by Jonas [8] and Watson and Cline.[9] They consist of acid plagioclase, potash feldspar, hypersthene, augite, quartz and some biotite. Accessory minerals are apatite, ilmenite, rutile, zircon, and in places garnet and pyrite. The phenocrysts are chiefly orthoclase and microcline with perthitic albite and included blebs of quartz. The plagioclase appears to have been originally oligoclase but it has been later altered hydrothermally to albite so that in places none of the oligoclase remains. In other localities practically all of the plagioclase is anti-perthitic oligoclase. The striking difference between the granodiorite of this area and the formation in general is the great amount of hydrothermal activity that has occurred here. Twenty-five slides taken from points distributed over the area all showed hydrothermal action to a marked degree. Chess-board albite is developed from microcline; plagioclase is corroded by "tear-drop," or lobate quartz; and abundant albite with epidote and calcite is altered from oligoclase. The latter is seen as either fine-grained aggregates or as individual minerals. Uralite, chlorite, sericite, and biotite are abundant. There are other indications of replacement,

[8] *Op. cit.*, pp. 50–55.

[9] Watson, T. L. and Cline, J. H.: Hypersthene syenite and related rocks of the Blue Ridge, Virginia. G. S. A. Bull. 27: 198–204, 1916.

evidenced by replacement veinlets of albite and biotite cutting through perthitic phenocrysts of potash feldspar. Myrmekite, a vermicular intergrowth of quartz and plagioclase feldspar, and a peculiar vermicular intergrowth of quartz and garnet also indicate solution action. These hydrothermal evidences, although noted in the granodiorite described from other localities, are stressed here because of their greater intensity and their significance in the theory to be postulated for the origin of the nelsonites.

Anorthosite.—Anorthosite has attracted widespread interest both because of its unusual character and because of the rutile that it contains. This body is roughly elliptical in shape, extends for 14 miles along the strike and has a maximum width of approximately 2½ miles. The anorthosite occurs mainly in Nelson County, but it extends about two miles south into Amherst County.

The anorthosite is a white to gray granulated rock composed, according to Ross,[10] essentially of sodic plagioclase with lesser amounts of potash feldspar and blue quartz. Minor constituents are apatite, zircon, biotite, graphite, muscovite, epidote, zoisite, kaolinite, calcite, leucoxene, garnet and chlorite. Locally, rutile and ilmenite are abundant.

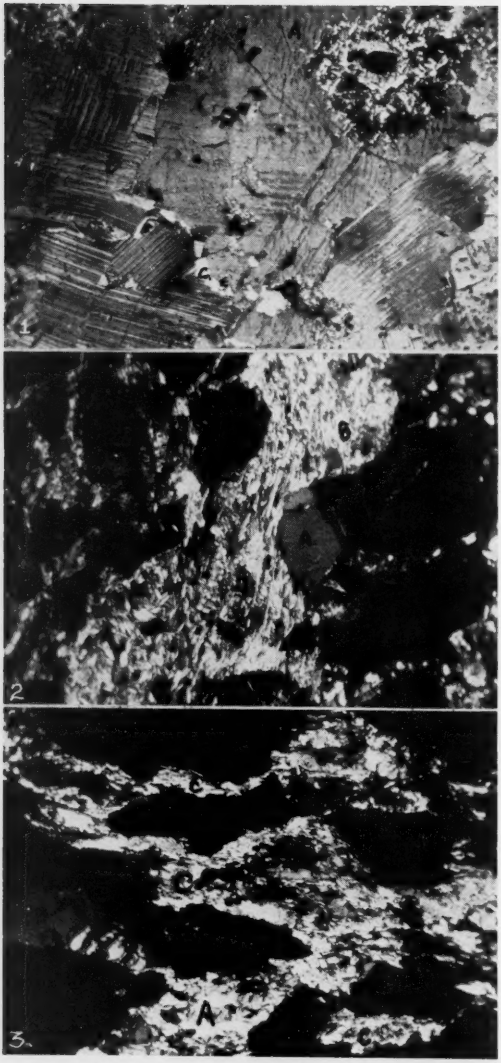
Specimens taken from the dumps of the recently opened quarry of the Old Dominion Mineral Company located on the southern bank of Piney River in Amherst County, two miles west of U. S. Route 29, show excessive development of chess-board albite (Fig. 1). Since this type of albite is supposed to result from the action of sodic waters on microcline, it would indicate that here the original feldspar was chiefly microcline. Otherwise, anorthosite examined in Amherst County conforms with the general description given by Ross.

The first detailed work on anorthosite was done by Watson and Taber[11] who concluded that the rock could not be a pegmatite, but was a syenitic differentiate of the common magma that gave rise to the main rock types of the area. Ross,[12] in his work on the

[10] Ross, C. S.: Titanium deposits of Roseland district. Int. Geol. Cong. Guidebook 11, Northern Virginia, pp. 29–36, 1933.

[11] *Op. cit.*, pp. 68–91.

[12] Ross, C. S.: *op. cit.*, p. 30.



FIGS. 1–3.

anorthosite suggested a pegmatitic origin formerly, but in a later paper,[13] he concluded that the anorthosite was introduced as a mush of crystals. The injection zone surrounding the body represents residual magma forced out of the spaces between grains of the partly crystallized rock, by filter-press action, during intrusion and consolidation.

The contact between the anorthositic body and the surrounding Lovingston gneiss was noted by the other workers to be a gradational one. Watson and Taber's[14] conclusion that this border area was originally gabbro, which has been so altered as to resemble a granodiorite, and Ross' opinion that the border rocks were formed from residual magma forced from the anorthosite by filter pressing, both indicate that on its edges the body is not true anorthosite. About five miles of the contact was mapped in Amherst County and at every locality where residual decay had not entirely destroyed the rocks, a band of altered rock varying in width from about one hundred feet to three-fourths of a mile was found between the anorthosite and the Lovingston. The lithology and mineral content of this rock are almost identical with the hydrothermally altered granodiorite from other parts of the area.

The anorthosite body is aligned with the small granodiorite body and is separated from it by only about a mile of highly al-

FIG. 1. Photomicrograph of anorthosite from Dominion Mineral Company quarry. *A*—Antiperthitic calcic albite; *B*—chess-board albite; *C*—interstitial quartz; dark grain is ilmenite which is surrounded by epidote. × 25.

FIG. 2. Photomicrograph of hard ore from the quarry of the Southern Minerals Products Company. *A*—large apatite grains. *B*—matrix of later minerals, composed of uralite, actinolite, chlorite, sericite and some quartz. Black mineral is ilmenite. × 25 Polarized light.

FIG. 3. Photomicrograph of "fresh" nelsonite from Lucian Burley property, 5 miles southwest of Amherst. *A*—matrix composed of uralite, actinolite, chlorite, and some quartz. *B*—large apatite grains. Black mineral is ilmenite. Note at "*C*" the apparent replacement of ilmenite by the minerals of the matrix. × 25 Polarized light.

[13] Ross, C. S.: Mineralization of the Virginia titanium deposits. Amer. Min., 21, No. 3: 143–146, 1936.

[14] *Op. cit.*, pp. 79 and 91–94.

tered Lovingston gneiss. This gneiss is also veined by small pegmatite dikes that originated in the granodiorite.

A study of the small amount of anorthosite exposed in Amherst County may not warrant an interpretation of origin for the entire body, but the following facts appear pertinent: (1) the gradational contact of the anorthosite with the granodiorite; (2) absence of direct contact of the anorthosite and the Lovingston; (3) the similarity between the feldspars of the anorthosite and the granodiorite; (4) the close association of the two rocks; (5) the similar types of alteration of the granodiorite and anorthosite; (6) the presence of other similar, smaller pegmatitic bodies in the granodiorite in other parts of the area. The above facts seem to point to pegmatitic differentiation of the granodiorite as the origin of the anorthosite rather than to a separate intrusion. This idea has been suggested before by Jonas [15] because of the intimate association of the anorthosite with the granodiorite.

Hydrothermally Altered Lovingston.—As stated before, all the rocks of the area have been altered hydrothermally to a greater or less degree. However, the Lovingston in proximity to the granodiorite intrusion has been so altered as to lose many of its original characteristics, and, therefore, merits a separate discussion.

These rocks appear in the field to be Lovingston gneiss with granodiorite characteristics. They are cut by a multitude of pegmatite dikes varying from an inch or less up to about six feet in width.

The hydrothermally altered Lovingston is a black and white, even-granular to porphyritic rock with weak but still discernible gneissic texture. The microscopic character of this rock differs from the normal Lovingston in the following ways: The biotite is either partially or entirely altered to chlorite. It is not in separated bands, but disseminated through the rock. Ilmenite has become very abundant, and clinozoisite, epidote, hornblende, and actinolite are the dominant minerals of the rock. Zircon is much more abundant and is associated with the ilmenite. Sphene, in the vicinity of the nelsonite dikes, shows twinning lamellae, probably indicating stress. Graphite is present all through this al-

[15] *Op. cit.*, pp. 54–55.

tered rock, but is especially abundant in the vicinity of the nelsonite dikes. Since the graphite cannot be distinguished from the ilmenite in thin sections, a heavy mineral separation is necessary to determine its presence. Pyrite is present in small amounts increasingly abundant towards the vicinity of the nelsonite dikes. Hematite, present in all the hydrothermally altered rocks, increases markedly in abundance in the vicinity of the nelsonites. Here veinlets of hematite, graphite (?) and ilmenite cut across the oligoclase. The quartz is definitely of two generations. The original quartz of this Lovingston is coarse grained, ragged, and filled with impurities. The later quartz is fine grained, fresh, and rutilated and occurs in veinlets as well as in disseminated grains. Crushed colorless garnets are also present in the rocks in proximity to the dikes. The albite is pink, resembling closely the feldspar in the pegmatite dikes.

The pegmatite dikes occur almost exclusively in the hydrothermally altered Lovingston. They are even granular and composed chiefly of perthitic microcline, albite, rutilated quartz, crushed garnets, zircon, and large apatite grains. Later minerals are zoisite, biotite, sericite, hematite, leucoxene, sphene, quartz, chlorite and chess-board albite. Small discontinuous veinlets of biotite, zoisite, hematite and graphite (?) commonly terminate in masses of epidote. Myrmekite is developed also.

Where the hydrothermally altered Lovingston is in contact with true granodiorite, there is developed in the former a series of parallel joints averaging one inch apart and parallel to the contact. These are exposed on the surface to variable distances from the contact depending on whether the contact is at a steep or low angle. These joints are superimposed on the original gneiss bands of the Lovingston and, at the contact, almost obliterate them. The joints decrease in abundance, dying out several hundred feet from the Lovingston granodiorite contact. These features are interpreted as having been formed during the emplacement of the granodiorite and would fall under the heading of marginal structures. This would imply a forceful emplacement for the granodiorite. Another fact to support this hypothesis is that on the

eastern side of the small body (Fig. 4) away from the contact the intense alteration abates as the joints begin to fade out. Also, these joints locally do not follow the general trend of the rocks but vary in strike with the contact line, always keeping parallel to it. None of these joints were found in the granodiorite.

The interesting and suggestive point about these joints is that they appear in only one other place in the area, namely, in the hydrothermally altered Lovingston in proximity to the nelsonite dikes. Here the joints are much less distinct and much closer together. They are almost vertical and die out a few feet away from the contact of the nelsonite and the hydrothermally altered Lovingston. Because of the extreme weathering of the dikes and the surrounding rocks the presence of these joints could not be verified in all cases, so this piece of evidence is not in itself conclusive of an igneous rather than a hydrothermal origin for the nelsonites.

Nelsonite.—Nelsonite is the name used by Watson and Taber [16] for a group of high titanium-phosphate-bearing rocks of igneous origin. The name was first suggested to cover those bodies occurring chiefly in Nelson County and composed normally of ilmenite and apatite. Watson and Taber later expanded the usage of the term "Nelsonite" to include many varietal forms of the rock, depending on its mineral composition. These varieties are (1) ilmenite nelsonite, (2) rutile nelsonite, (3) magnetite nelsonite, (4) biotite nelsonite, (5) hornblende nelsonite, and (6) gabbro nelsonite.

As to the origin of the nelsonites Watson and Taber [17] conclude: "They are thought to be basic segregations somewhat similar in mode of origin to the well-known segregations of titaniferous magnetite in gabbros. They represent the latest differentiations from the magma which gave rise upon cooling to syenite and the other igneous rock types of this area."

Watson and Taber apparently did not recognize the large areas of hypersthene granodiorite in this area. They assumed that all of the rocks of the area were differentiates of one magma and that

[16] *Op. cit.*, p. 100.
[17] *Op. cit.*, p. 69.

all were emplaced about the same time. From their mineral descriptions it is probable that the "gabbros" they found "intruding" the anorthosite, and the gradations to gabbro around the edges of the anorthosite body, are synonymous with granodiorite. But they thought this gabbro was merely the small dike-like segregations from the main quartz-monzonite magma, rather than part of the huge batholith that comprises the core of the Blue Ridge Mountains.

There is no doubt, from the similarity of their constituent minerals that the magmas which gave rise to the Lovingston gneiss and the hypersthene granodiorite must have been very similar in composition, but the proofs given elsewhere in this paper indicate that a long time interval must have elapsed between their respective intrusions.

The nelsonite dikes of Amherst County all occur within the area designated as hydrothermally altered Lovingston. There are many more of these dikes in Amherst County than has heretofore been supposed. The reason for this is that the deep residual weathering, heavy undergrowth, and the rugged and mountainous nature of the topography makes the outcrops difficult to find.

All of the surface exposures of nelsonite are not weathered to the same degree. In some exposures only the ilmenite, limonite and small grains of osteolite remain, whereas in others, nearly all of the minerals of the dike are relatively fresh. Phenocrysts of ilmenite and apatite, with the matrix composed of fibrous hornblende, biotite altering to chlorite, sphene, hematite, and quartz are the chief minerals. Another dike was found that appears to be composed essentially of ilmenite with intergrown magnetite and sphene. The writer[18] has described this occurrence as containing three parts ilmenite and two parts magnetite. It was then stated that the dike occurs in the lighter portion of the granodiorite. However, later work has shown this dike to be in the hydrothermally altered Lovingston. In fact, extensive search revealed none of the bodies in the granodiorite proper, although their occurrence has often been noticed in the anorthosite.

[18] Some rocks and minerals of Amherst County, Virginia (Abstract). G. S. A. Bull. 49, No. 12, pt. 2: 1955, 1938.

The quarry of the Southern Minerals Company in the northern portion of Amherst County provides an excellent place to study the composition of nelsonite. It is about 75 feet in depth and extends well below the zone of weathering. A vertical section in this quarry shows the following features:

1. Gossan Ore—The term gossan is here applied to the surface outcrops above the weathered ore from which all except the most stable constituents have been removed. The rock is brown in color and consists chiefly of crystals of ilmenite and lesser amounts of apatite, which is altered to osteolite, and limonite. Stringers of chlorite altered from biotite and sericite occupy minute fractures in the ilmenite and apatite grains. The limonite is apparently filling features.

2. Weathered Ore—The weathered ore is also brown in color and extends from just below the surface to a depth of approximately 50 feet. It is very soft and is called by the quarrymen "lateritic ore." The ore consists of ilmenite with lesser amounts of graphite, apatite, biotite, and some quartz. Quartz, replacing the apatite, is in a much smaller proportion than it appears in the hand specimen. The ilmenite has a parting almost at right angles causing it to fracture into rectangular masses.

3. Hard Ore—The hard ore comes from the deepest portion of the quarry and has suffered very little weathering. It is green in color, with the metallic minerals and apatite composing the phenocrysts. They are, in order of abundance, ilmenite, apatite, pyrite and pyrrhotite, and graphite, and appear to be dominant over the matrix, which is composed of hornblende, actinolite, biotite, uralite, chlorite, sphene, magnetite, rutile, hematite and quartz (Fig. 2). Polished sections of these ores show biotite, hornblende, and chlorite apparently replacing the ilmenite and apatite.

A polished section from the ilmenite magnetite dike on U. S. Route 60 shows discontinuous veinlets of actinolite, chlorite and garnet replacing the metallic minerals. If this apparent replacement is true, then the metals must be of an earlier origin than the non-metals.

A nelsonite dike on the Lucian Burley property five miles south-

west of Amherst was observed to carry appreciable amounts of allanite (Fig. 3). This mineral occurs in pockets in the dike and has been noted by Pegau,[19] who stated that the mineral is found in pockets of granodiorite associated with nelsonite. He also noted the prevailing country rock to be "a heavily injected quartz monzonite." Directly in line with this dike across Pauls Mountain, the writer found more allanite lying in large pieces on the surface. There were also specimens of ilmenite with much associated titanite and sericite. The source of this float could not be determined.

At the historic locality of Little Friar Mountain, from which so many specimens of allanite have been collected, the mineral was observed to occur directly in the granodiorite. The allanite here is associated with feldspar and has been called a pegmatite. No ilmenite or rutile was observed from this locality.

ORIGIN OF THE NELSONITE.

The foregoing facts have been assembled to show the reason for formulating the following theory for the origin of the nelsonite dikes. It is believed that the constituents forming the dikes were given off from the granodiorite magma upon cooling, and that these dikes rose upward through overlying Lovingston gneiss. Contemporaneous and later solutions rising from the cooling granodiorite magma altered the Lovingston and the nelsonite dikes, forming the hydrothermally altered Lovingston, and altering the dikes so that their original composition of ilmenite and apatite was supplemented by the minerals, uralite, hornblende, biotite, chlorite and perhaps allanite. There is no way of determining whether the allanite was primary or a later addition.

The accompanying generalized cross section (Fig. 4) taken approximately along U. S. Route 60 from near Amherst on the southeast to Swan Hill School in the main granodiorite body on the northwest will provide an idea of the writer's conception of the relation of the rocks that gave rise to and determined the location of the nelsonites. The extreme hydrothermal alteration of the granodiorite, the marginal joints, the presence of peg-

[19] Pegau, A.: Pegmatite deposits of Virginia. Virginia Geol. Surv. Bull. 33: 96.

matites and nelsonites in the associated Lovingston, and the hydrothermal alteration of this Lovingston all tend to support the theory that here the roof of the intrusion is either exposed, or, where it is not exposed, is very near the surface.

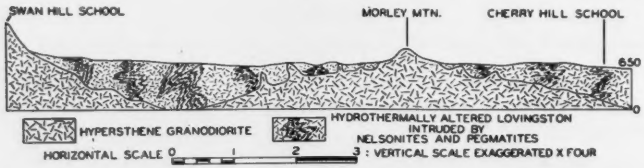

SWAN HILL SCHOOL
MORLEY MTN.
CHERRY HILL SCHOOL
650
0
HYPERSTHENE GRANODIORITE
HYDROTHERMALLY ALTERED LOVINGSTON INTRUDED BY NELSONITES AND PEGMATITES
HORIZONTAL SCALE 0 1 2 3 : VERTICAL SCALE EXAGGERATED X FOUR

FIG. 4. Diagrammatic section of the relationships of the hypersthene granodiorite, hydrothermally altered Lovingston gneiss, nelsonite and pegmatites.

The points in favor of the suggested origin for the nelsonites, the evidence of which has already been discussed, may be summarized as follows:

1. The occurrence of the pegmatite and nelsonite dikes only in the intensely altered Lovingston and in the anorthosite.
2. The presence of ilmenite-apatite float over the true granodiorite, without the associated nelsonite dikes, indicating that the preexisting dikes in the altered Lovingston above the granodiorite have along with the Lovingston been destroyed by weathering and erosion.
3. The noted occurrence of allanite in the true granodiorite not associated with ilmenite at Little Friar Mountain, and the occurrence of allanite in a nelsonite dike that intrudes the Lovingston, but no allanite found in the Lovingston unaccompanied by nelsonite.
4. Apatite and ilmenite universally present as the chief accessories in the granodiorite.
5. The nelsonite dikes always being associated areally with the pegmatites, whose mineral relations with the granodiorite prove almost conclusively that they are related to that body.

6. Few nelsonite dikes occur at any localities other than Nelson and Amherst counties. At no other place so far as the writer can determine, is the granodiorite-Lovingston relation similar to that in these counties (Fig. 4). The cupola shape of the intrusion of granodiorite in this locality left an ideal location between it and the main mass for the preservation of the covering of altered Lovingston and the dikes that intruded it.
7. The dikes are nearly always parallel to the gneissic structure of the Lovingston, indicating that their trend was controlled by this structure. Since this structure is caused by regional metamorphism, the nelsonite bodies could not be segregations of the rock in which they occur, as postulated by Watson and Taber.[20]
8. The widespread similarity of composition of all the dikes. It is seen from the suite of specimens taken from various levels in the dike being worked at Piney River that the biotite, hornblende, ilmenite and magnetite nelsonite of Watson can all be found in the same dike and are not separate intrusions but merely varying degrees of intensity of the later hydrothermal replacement exposed by variations in the depth of weathering. No gabbro nelsonites or rutile nelsonites were found in Amherst County.

It is realized that although the reasons given above prove almost conclusively the genetic relationship of the nelsonites to the granodiorite, they do not entirely eliminate the possibility of a hydrothermal origin for the dikes. Indeed, the facts listed could be made to support the theory that there were two periods of solutions, the first depositing the metallic minerals and apatite, and the second bringing in the non-metallic minerals that replaced the metallic ones. However, the following additional evidence points to an originally solid intrusion of the dikes.

1. The dikes have an even-granular texture throughout that shows little variation.

[20] *Op. cit.*, pp. 151–155.

2. Their occurrence in dikes with walls that are always sharply defined.
3. Inclusion of apatite in ilmenite and vice-versa, indicating simultaneous crystallization.
4. The suites of typical hydrothermal minerals are later than the ilmenite and apatite and can be observed replacing them.
5. Since solutions have been extremely active in the region surrounding the dikes, if ilmenite and apatite were carried by these solutions, the proportion of these minerals in the intensely altered Lovingston would be much greater than that in the normal Lovingston. In the majority of instances this was not observed to be the case.
6. The existance of marginal joints observed in some instances in the rocks surrounding the dikes.

CONCLUSIONS.

The evidence offered for a solid origin for the nelsonites and against a purely hydrothermal origin necessarily cannot be conclusive until the dikes are further exploited. However, the main purpose of this paper is to establish a definite genetic relation between the nelsonite dikes and the hypersthene granodiorite. According to the evidence presentetl, the nelsonite dikes are definitely younger than their host rock, the Lovingston gneiss; they were formed at about the same time as the emplacement of the granodiorite; and the only genetic connection between the anorthosite and the nelsonites is that both are related to the hypersthene granodiorite.

PROSPECTING FOR NELSONITES.

It is thought for reasons given above, that there are many undiscovered dikes of commercial value in Amherst County. Since a dike need be only twenty feet wide to be of commercial value, this can easily be understood.

It is believed that only a few of the total number of nelsonite dikes are associated with the anorthosite. The occurrence of this anorthosite body did not control the formation of the dikes and there are more outside the bounds of the anorthosite than in it.

All the area of Lovingston gneiss that is designated as intensely hydrothermally altered Lovingston, and which is, therefore, underlain by granodiorite, is a possible source for the nelsonites. Surface prospecting in this region, because of the deep residual weathering, is not too satisfactory. Prospecting should be done with a magnetometer in the fall of the year when the vegetation is dead. Because of the magnetic quality of the ilmenite, a weak needle can be used to advantage.

It is thought by the writer that thorough exploration of this portion of Amherst County will reveal probably large domestic reserves of titanium and phosphate which have heretofore been little suspected.

GEOLOGY DEPARTMENT,
CORNELL UNIVERSITY,
April 5, 1940.

SOLUTION AND PRECIPITATION OF LEAD AND ZINC SULPHIDES IN SODIUM SULPHIDE SOLUTIONS.

F. GORDON SMITH.

ABSTRACT.

Sodium polysulphide and sodium hydrogen sulphide solutions were heated and then slowly cooled in contact with amorphous lead and zinc sulphides in a graphite-lined steel bomb. From a microscopic study of the resultant crystals, it was concluded that both lead and zinc sulphide are soluble to a limited extent in such solutions at elevated temperatures, and that sphalerite crystallizes out before galena on cooling.

INTRODUCTION.

THE problem of how the metallic sulphides are transported in natural hydrothermal solutions has long been a controversial one. The question is complicated by the great number of minerals that are precipitated, but it can be simplified to some extent if only two minerals are chosen for study—two that precipitate out of solution at nearly the same time in nature, in a definite and constant sequence and which contain metals that are equivalent and have similar chemical properties. Sphalerite and galena fulfill these conditions and it is with these two sulphides that the present investigation deals.

The assumption is made that sphalerite and galena are precipitated in nature from the same type of solutions, the dominant control over the precipitation being the fall in temperature with time at any one place in the vein and the fall in temperature with vertical extent of the vein. From the recorded parageneses and the examples of vertical zoning, it appears that sphalerite precipitates out of solution before galena.

The argument is that if both lead and zinc sulphides are soluble in solutions of a composition possible in nature, and if sphalerite crystallizes before galena during cooling, then such solutions *may* have acted as the transportation agents for these two sulphides in nature.

Kristofferson[1] has shown that the order of volatility of the chlorides of lead and zinc is the reverse of the order to be expected if the metals are transported in this form, since zinc is precipitated closer to the magma chamber than lead, although zinc chloride is more volatile than lead chloride.

According to Verhoogen's results,[2] the solubility of the sulphides of lead and zinc in aqueous solutions giving the simple metallic ions is also the reverse of the order to be expected if the metals are transported in this form, since zinc sulphide is more soluble than lead sulphide.

According to the theory of sulphide ore deposition from alkaline solutions, the metallic sulphides are transported as double sulphides with alkaline sulphide in aqueous solutions. Although this theory had its roots in the beginning of modern economic geology in the works of Emmons[3] and Becker[4] and now has considerable support, it has not been demonstrated that the order of solubility of the metallic sulphides is the same as the order of deposition in nature.

Gruner[5] has shown that the sulphides of mercury, arsenic and antimony are quite soluble in solutions of alkaline sulphide, but that probably the sulphides of the other metals are not. Since these three soluble sulphides are the last of the sulphides to precipitate out in nature, the first approximation to the order of solubility fits the natural order of deposition.

Freeman[6] showed that the double sulphides of zinc and sodium and lead and sodium can be formed by fusing the constituent sulphides together and that the double sulphides are decomposed by water to sodium sulphide and zinc and lead sulphides. The

[1] Kristofferson, O. H.: Hydrothermal experiments with lead and zinc minerals. ECON. GEOL., 31: 185, 1936.

[2] Verhoogen, J.: Thermodynamical calculations of the solubility of some important sulphides, up to 400° C. ECON. GEOL., 33: 34 and 775, 1938.

[3] Emmons, S. F.: Geology and mining industry of Leadville, Colorado. U. S. Geol. Surv. Mon. 12, 1886.

[4] Becker, G. F.: Quicksilver deposits of the Pacific slope. U. S. Geol. Surv. Mon. 13, 1888.

[5] Gruner, J. W.: Solubility of metallic sulphides in alkaline sulphide solutions. ECON. GEOL., 28: 773, 1933.

[6] Freeman, H.: Genesis of sulphide ores. Eng. & Min. Jour., 120: 973, 1925.

sodium sulphide goes into solution and the zinc and lead sulphides form unstable colloidal solutions.

Allen, Crenshaw and Merwin [7] obtained good crystals of sphalerite by heating amorphous zinc sulphide in a solution of sodium sulphide to 350° C. in a steel bomb.

There appears to be substantial evidence that double sulphides of sodium and some of the metals are capable of existence, even though there is very little data on the limits of their stability. Also, there is good ground for the belief that hydrothermal solutions, for the major part of their course, are alkaline sulphide solutions.[8] It remains to be proved that alkaline sulphide solutions are solvents for the metallic sulphides found in hydrothermal veins and that the order of precipitation of the sulphides during the cooling of such solutions is similar to the natural order of deposition.

The experimental method used in this investigation is heating alkaline sulphide solutions with lead and zinc sulphides, cooling slowly and determining the relationship of the crystals of galena and sphalerite so produced by applying the usual criteria of order of deposition in open space.

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APPARATUS AND CHEMICALS USED.

The bomb used to contain the solutions was constructed of nickel-chrome-molybdenum alloy steel. The inside diameter was two inches and the height, three inches. The wall was one inch thick. An inner lining of Acheson electrode graphite was

[7] Allen, E. T., Crenshaw, J. L., and Merwin, H. E.: The sulphides of zinc, cadmium and mercury. Amer. Jour. Sci. (4), 34: 341, 1912.

[8] Graton, L. C. and Bowditch, S. I.: Alkaline and acid solutions in hypogene zoning at Cerro de Pasco. Econ. Geol., 31: 651, 1936.

machined to fit inside the bomb and a graphite cover was made to fit on top of the graphite lining. In this way a layer of graphite about 0.5 cm. thick separated the solution from the steel and although it was porous, it greatly lowered the rate of reaction between the sodium sulphide and the steel.

The internal volume of the bomb was different in the first experiment than in the following two, due to a differently shaped graphite cover. The graphite lining was cleaned after each experiment by rubbing the surface clear of adhering solid material and by repeated leaching with distilled water. In each case the graphite lining was saturated with water before the charge was added.

The bomb was heated by means of a resistance furnace and the temperatures were recorded by means of a chromel-alumel thermocouple and potentiometer.

The sodium sulphide was Baker's analyzed reagent and was weighed as $Na_2S.9H_2O$ and as Na_2S when desiccated at about 150° C. The sodium-hydrogen sulphide was prepared by dissolving sodium sulphide in boiled distilled water and bubbling through the solution hydrogen sulphide generated by means of a Kipp generator. Sulphur was added as flowers of sulphur.

Lead and zinc were added as the chlorides. Lead and zinc chlorides in equi-molecular ratio were fused, cooled and broken into pieces. One or two fragments were weighed and added to the solution in the bomb just before sealing.

The space over the solutions was occupied by air in the first two experiments and by hydrogen sulphide in the third.

EXPERIMENTAL PROCEDURE.

The experiments were simple. In the first two, water, sodium sulphide, sulphur, lead chloride and zinc chloride were weighed out and placed in the bomb. The bomb was then sealed, placed in the furnace, heated to the desired temperature and then cooled slowly. In the third experiment, a prepared solution of sodium-hydrogen sulphide was placed in the bomb with lead chloride and zinc chloride and the air was displaced with hydrogen sulphide just

before sealing. The bomb was then heated and cooled as before.

The sulphur dissolved in the sodium sulphide solutions in the first two experiments to form solutions of sodium polysulphide.

The lead and zinc chlorides in each experiment reacted at once with the sodium sulphide (or polysulphide or hydrosulphide), forming amorphous lead and zinc sulphides, which then apparently dissolved to some extent in the solutions as the temperature rose and precipitated out in minute, nearly euhedral crystals as the solutions cooled. The presence of sodium chloride in the solutions is not objectionable from a geological point of view, since at least some natural ore-bearing solutions contain appreciable quantities of it.[9]

The volume of the solutions was made a little less than half the internal volume of the bomb, so that assuming a thermal expansion similar to that of pure water, the solutions completely filled the inside of the bomb before the critical temperature of pure water (374° C.) was reached. Even if critical conditions were reached at the highest temperature (425° C.), which is doubtful, Ingerson[10] has pointed out that critical phenomena of a solvent do not affect the solubility of a solute so long as there is no change in the density of the solution on passing through the critical interval.

On opening the bomb, the insoluble material was washed free of sodium sulphide and an estimate was made of the percentage of amorphous (or near-amorphous) metallic sulphides that had not been recrystallized and the percentage that had been recrystallized. The crystalline material was then washed free of the amorphous sulphides, dried and mounted in balsam for examination under the microscope.

Drawings of the relationship of the crystals were made instead of photomicrographs because of the difficulty of bringing into sharp focus all parts of the crystal groups at the magnification necessary.

[9] Buerger, M. J.: Negative crystal cavities in certain galena and their brine content. Amer. Min., 17: 228, 1932. Newhouse, W. H.: Composition of vein solutions as shown by liquid inclusions. Econ. Geol., 27: 419, 1932.

[10] Ingerson, E.: Relation of critical and supercritical phenomena of solutions to geologic processes. Econ. Geol., 29: 454, 1934.

Experiment A.—The charge in the bomb was made up as follows:

$Na_2S.9H_2O$	25.21 gm.
S	11.02 gm.
$PbCl_2$	0.529 gm.
$ZnCl_2$	0.259 gm.

The internal volume of the bomb was 52.8 cc.

The bomb was heated to 415° C. in three hours and cooled to 25° C. in 19 hours. Much H_2S escaped on opening. Crystals of what appeared to be $Na_2S.9H_2O$ and crystals of sulphur rested on the bottom under a yellow solution, which gave a strong test for the sulphate radical. Crystals of what looked like galena lined the graphite walls.

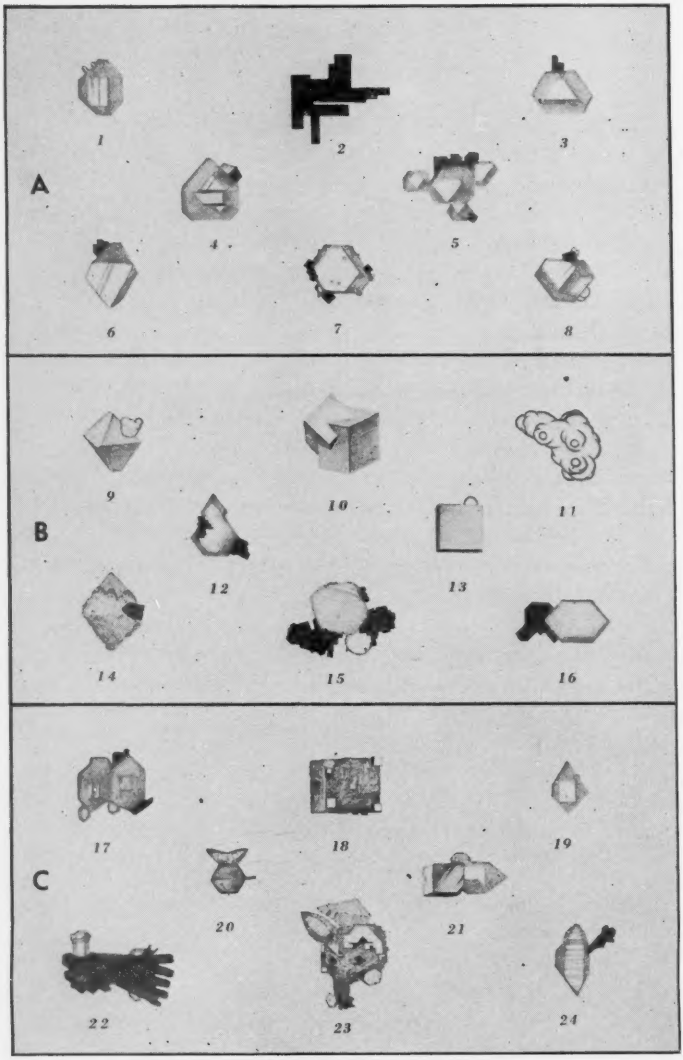
The sodium sulphide was removed by dissolving in water and the sulphur was removed by dissolving in carbon disulphide. The crystals on the graphite wall were washed down with a stream of water, dried and embedded in balsam for examination. Practically all of the metallic sulphides seemed to have been recrystallized, no more than about 5 per cent being amorphous.

The crystals were of sphalerite and galena. Their relationship is shown in Figs. 1 to 8. The habit of the sphalerite was octahedral, often modified by the cubic faces; no distinction between the complementary tetrahedrons was observed. A small amount of zinc sulphide was present in very small crystals and amorphous globular forms. The habit of the galena was cubic, often elongated in one or two directions.

Not often did a crystal group contain both sphalerite and galena, but when it did, the relations were as shown, and the order of events was interpreted as follows:

(1) octahedrons of sphalerite crystallized first,
(2) cubes of galena crystallized, sometimes on the earlier sphalerite, and,
(3) a small amount of zinc sulphide still in solution precipitated out in minute crystals and amorphous forms.

The crystal faces of sphalerite were slightly etched, in lines parallel to one of the faces. The crystal faces of galena were un-



FIGS. 1–24.

etched. This may mean that after the sphalerite was formed, the solution, on further cooling, attacked it slightly, carrying off some

FIG. *A*, transmitted light. *1*. Crystal of light-colored sphalerite with small sphalerite crystals on a tetrahedron face. *2*. Irregular crystal of galena. *3*. Pseudo-octahedron of light-colored sphalerite with an irregular crystal of galena on a tetrahedron face. *4*. Crystal of light-colored sphalerite with a cubic crystal of galena on a tetrahedron face. *5*. Group of light-colored sphalerite crystals with cubic crystals of galena on the tetrahedron faces. *6*. Pseudo-octahedron of sphalerite with a group of cubic crystals of galena on a tetrahedron face. *7*. Crystal of light-colored sphalerite with cubic crystals of galena, small crystals of sphalerite and small amorphous particles of zinc sulphide on some of the faces. *8*. Crystal of light-colored sphalerite with a cubic crystal of galena and a colloform particle of amorphous zinc sulphide on two of the faces, and amorphous zinc sulphide on the cubic crystal of galena.

FIG. *B*. *9*. Pseudo-octahedron of brown sphalerite with a colloform mass of amorphous zinc sulphide on a tetrahedron face. *10*. Penetration twin of cubes of galena. *11*. Colloform mass of amorphous zinc sulphide. *12*. Corroded crystal of light yellow sphalerite with irregular crystals of galena on two of the faces. *13*. Cubic crystal of galena with a colloform hemisphere of amorphous zinc sulphide on a cube face. *14*. Pseudo-octahedron of light brown sphalerite with a crystal of galena on a tetrahedron face and amorphous zinc sulphide covering most of the faces. *15*. Corroded crystal of yellow sphalerite with aggregates of cubic crystals of galena on some of the faces, a sphere of amorphous zinc sulphide resting partly on the sphalerite and partly on the galena, and two minute particles of lead sulphide on the surface of the sphere of amorphous zinc sulphide. *16*. Corroded crystal of light-colored sphalerite with an irregular crystal of galena on two tetrahedron faces.

FIG. *C*. *17*. Corroded crystal group of brown sphalerite with corroded crystals of galena on two tetrahedron faces of one of the sphalerite crystals. *18*. Deeply etched cubic crystal of galena. *19*. Crystal of pale yellow wurtzite showing the hexagonal prism and hemimorphic hexagonal pyramids. Extinction direction (*c*-axis) vertical. *20*. Corroded crystal of dark brown sphalerite with colorless wurtzite crystals on one face. *21*. Etched cubic crystal of galena with a pale yellow crystal of wurtzite on one cube face. *22*. Corroded crystal group of galena with three nearly colorless crystals of wurtzite. *23*. Reflected and transmitted light. Deeply etched crystal of brownish black sphalerite with three pale yellow crystals of wurtzite. *24*. Crystal of colorless wurtzite with dendritic galena on a prism face.

Note: *The magnification is approximately 300 diameters in all the figures.*

zinc sulphide which it later deposited as the microcrystalline and amorphous material.

The perfection of crystal form of the sphalerite and galena suggest that they crystallized from a true solution and the amorphous zinc sulphide would suggest formation from a colloidal solution.

Experiment B.—The following were placed in the bomb:

Na_2S	17.51 gm.
S	7.69 gm.
H_2O	5.00 gm.
$PbCl_2$	1.028 gm.
$ZnCl_2$	0.502 gm.

The internal volume of the bomb was 67.5 cc.

The bomb was heated to 425° C. in 2 hours and cooled to 30° C. in 20 hours. Much H_2S escaped on opening. Crystals of Na_2S .$9H_2O$ were at the bottom, under a yellow solution, which gave a strong test for the sulphate radical. A few crystals of what looked like galena could be seen adhering to the graphite wall.

The sodium sulphide was removed by dissolving in water. The insoluble material was made up of small crystals of metallic sulphide and also amorphous and near-amorphous metallic sulphide. About 70 per cent seemed to be crystalline. The crystals were washed free of the amorphous material and then treated with carbon disulphide to remove any sulphur, and mounted in balsam for examination.

The crystals were found to be of sphalerite and galena and there was also some zinc sulphide present as amorphous globular forms. The habit of the sphalerite was octahedral, occasionally showing the cubic faces. The habit of the galena was cubic, sometimes in penetration twins.

The relations between the sphalerite and galena and amorphous zinc sulphide were found to be the same as in Experiment A, as shown in Figs. 9 to 16, but with these minor differences:

(1) most of the crystals of sphalerite were much corroded,
(2) the percentage of amorphous zinc sulphide was greater,
(3) a very small amount of dendritic galena was deposited later than the amorphous zinc sulphide.

The greater amount of etching of the early-formed sphalerite, combined with the greater amount of amorphous zinc sulphide is thought to be further evidence that the solution attacked and dissolved some of the sphalerite and deposited it later as amorphous zinc sulphide, probably from colloidal solutions.

Experiment C.—A solution of sodium hydrogen sulphide was prepared as follows: 26.45 gm. $Na_2S.9H_2O$ was dissolved in a small amount of boiled distilled water and saturated with H_2S at room temperature; distilled water was added to bring the volume to nearly 30 cc. and it was again saturated with H_2S; distilled water was then added to make the volume exactly 30 cc., and it was again saturated. Into the bomb was pipetted 28 cc. of this solution, corresponding to 24.69 gm. $Na_2S.9H_2O$ and to this was added 2.355 gm. $PbCl_2$ and 1.152 gm. $ZnCl_2$. The air over the solution was displaced with H_2S just before sealing.

The inside volume of the bomb was 67.5 cc.

The bomb was heated to 410° C. in two hours and cooled to 30° C. in 18 hours. On opening, a small amount of H_2S escaped. The solution was colorless and contained much flocculent material in suspension. The solution gave a faint test for the sulphate radical. Crystals of metallic sulphides lined the graphite wall where the solution was in contact with it and for 0.4 cm. above the level of the solution.

The crystals were washed down from the sides of the graphite lining, freed from sodium sulphide and flocculent metallic sulphides, dried and mounted in balsam. About 20 per cent of the insoluble material was crystalline.

The crystals were of sphalerite, galena and wurtzite. Their relationship is shown in Figs. 17 to 24. The habit of the sphalerite was cubic, modified by the octahedral faces. The habit of galena was cubic, generally in dendritic aggregates and sometimes in dendritic forms showing no crystal faces. The wurtzite showed the hexagonal prism and hexagonal hemimorphic pyramids and often the place of the prism faces was taken by an oscillatory combination of pyramid faces.

From the relations of the crystals, the order of events was interpreted as follows:

(1) cubo-octahedrons of dark-colored sphalerite crystallized out first,
(2) aggregates of cubic crystals of galena crystallized out,
(3) the early-formed sphalerite was attacked, zinc sulphide was taken into solution and later deposited as light-colored wurtzite, and
(4) a small amount of lead sulphide still in solution deposited as microcrystalline dendritic aggregates.

It is possible that the sphalerite and cubic galena crystallized out of true solution and were both later attacked by the solution, which removed zinc and lead sulphides in colloidal form and deposited them again as wurtzite and dendritic galena. If this interpretation is correct, the order of deposition from true solution and from colloidal solution is the same, first zinc sulphide and then lead sulphide.

DISCUSSION OF THE RESULTS.

The solubility of lead and zinc sulphides in solutions of sodium polysulphide and sodium hydrogen sulphide is not very great, even in solutions as concentrated as were used in the above experiments, but there is good evidence that they *are soluble* and that the solubility increases with increasing temperature.

There are a number of factors that prevented the quantitative determination of the solubility of the two sulphides. The most important is that the solutions put in the bomb apparently change in character during heating and cooling. Sodium polysulphide in water is not stable, but reacts with the water to form sodium sulphate, sodium-hydrogen sulphide, hydrogen sulphide and sometimes free sulphur. Thus, the solutions used in the above experiments may be considered to be solutions of sodium-hydrogen sulphide with various amounts of sodium polysulphide, depending on the amount of sulphur added and on the temperature.

The ratio $S : Na_2S$ in the three experiments was as follows:

Experiment A, 1.35
Experiment B, 0.44
Experiment C, 0.00.

With the sulphur concentration as the dominant variable, and the interpretation of the crystal relationships as given above, the sulphur concentration then controlled to some extent the manner of crystallization of lead and zinc sulphides contained in the cooling solution.

In Experiment A, with a high concentration of sulphur, sphalerite and then galena crystallized on cooling. The sphalerite was then slightly etched, the solution dissolving away some zinc sulphide, which it later deposited on further cooling as minute crystals of sphalerite and as amorphous zinc sulphide.

In Experiment B, with a lower concentration of sulphur, sphalerite and then galena crystallized on cooling. The sphalerite was then corroded, the solution dissolving away some zinc sulphide which it deposited on further cooling as globular amorphous zinc sulphide. A very small amount of dendritic galena was deposited later than the amorphous zinc sulphide, and was probably derived in a similar manner from the early-formed galena.

In Experiment C, with no free sulphur, sphalerite and then galena crystallized on cooling. The sphalerite was then greatly corroded, the solution dissolving away much zinc sulphide which it deposited on further cooling as wurtzite. A small amount of dendritic galena crystallized out later than the wurtzite, and was probably derived in a similar manner from the early-formed galena.

The solution of the early-formed crystals and the redeposition as minute crystals of sphalerite, amorphous zinc sulphide, wurtzite and dendritic galena was probably due to colloidal dispersion and coagulation. If this explanation is correct, then sodium-hydrogen sulphide is a better peptizing agent than sodium polysulphide.

It was concluded that both galena and sphalerite are soluble in aqueous solutions of sodium polysulphide and/or sodium-hydrogen sulphide at elevated temperatures and that on cooling such solutions, *sphalerite crystallizes out before galena.* Since sphalerite appears to crystallize out before galena in cooling hydrothermal solutions in nature, then solutions of sodium polysulphide and/or sodium-hydrogen sulphide *may* be the type of solutions that have deposited these two minerals.

Summary and Conclusions.—1. In aqueous solutions of sodium polysulphide and sodium hydrogen sulphide, zinc sulphide and lead sulphide are soluble to a limited extent at elevated temperatures.

2. On cooling such solutions, zinc sulphide precipitates out before lead sulphide.

3. As the solutions cool, the order of events is as follows:

(*a*) sphalerite crystallizes in octahedrons or cubo-octahedrons,

(*b*) galena crystallizes in cubes,

(*c*) sphalerite is attacked by the solution which removes some zinc sulphide and deposits it later as small crystals of sphalerite, as amorphous zinc sulphide or as hexagonal hemimorphic crystals of wurtzite, and

(*d*) galena is attacked to a lesser degree and the dissolved lead sulphide is deposited later as microcrystalline galena.

4. The re-solution of the early-formed sphalerite and galena is probably due to colloidal dispersion.

5. The higher the concentration of sulphur in the solution, the less important are the later colloidal effects.

6. The higher the concentration of sodium hydrogen sulphide in relation to sodium polysulphide, the greater is the tendency for wurtzite rather than sphalerite to form from the later deposition of zinc sulphide from the colloidal state.

7. Since sphalerite is deposited before galena in nature, solutions of sodium polysulphide and/or sodium hydrogen sulphide *may* be the type of solutions active in the transportation and deposition of these two minerals in nature.

UNIVERSITY OF TORONTO,
TORONTO, ONTARIO,
Feb. 16, 1940.

MICROSCOPIC FEATURES OF ORE FROM THE SUNSHINE MINE.

RICHARD J. ANDERSON.

ABSTRACT.

The Sunshine Mine, Coeur d'Alene district, Idaho, is the leading silver mine in the United States. The vein is of the fissure type common to the district and is located on the north limb of the Big Creek Anticline. The deposit resembles Lindgren's "galena-tetrahedrite-siderite" type, of which the Wood River, Idaho, ores are representative. The important gangue minerals are siderite and quartz. Tetrahedrite is the silver-bearing mineral, but polished surfaces revealed no silver minerals in it. Presumably the silver is present as an isomorphous constituent of the tetrahedrite. The paragenesis is in keeping with the order of mineral deposition in silver deposits of this type. Pyrite was the earliest sulphide, followed by arsenopyrite, tetrahedrite, galena and chalcopyrite. The development of bournonite is common where the galena is in contact with the tetrahedrite.

INTRODUCTION.

THE presence of several rich silver veins in the area between Wallace and Wardner in the Coeur d'Alene District of northern Idaho was known in the early days of mineral exploration. Only in recent years, particularly since 1927, have these "Silver Belt" mines reached a position of economic importance. The largest producer in this group is the Sunshine Mine, located in the canyon of Big Creek. Production of 12,146,853 ounces[1] in 1937, and 11,352,986 ounces[2] in 1938, places it at the head of the silver producers in the United States. This high silver production is due chiefly to the unusually rich character of the ore. From a geologic viewpoint the deposit is not greatly complex, and microscopic examination of the ore shows a fairly simple mineralogy. The economic importance of the Sunshine Mine, however, warrants a description of the ore.

[1] Eng. and Min. Jour., 139: 94, 1938.

[2] Am. Bur. Metal Statistics, 19th Annual Report, p. 94, 1939.

Acknowledgments.—The writer is indebted to the officials of the Sunshine Mining Company, Kellogg, Idaho, for permission to collect a suite of ore specimens while in their employ. Mr. R. D. Leisk and Mr. R. F. Mahoney facilitated the collection of necessary material. The writer sincerely appreciates the assistance rendered by Mr. J. F. Edgar and Mr. S. K. Garrett in the subsurface work. Any merit in the photomicrographs is due to the kind assistance of Mr. D. W. Davis and Dr. A. F. Hagner. Especially helpful in laboratory work and in the preparation of the manuscript was the searching criticism of Professor Philip Krieger and Dr. Eugene Cameron of Columbia University. For their courtesy in reading the manuscript and for valuable advice the writer wishes to thank the staff of the Department of Geology of the University of Minnesota. Thanks are especially due Professors F. F. Grout and G. M. Schwartz for their friendly criticism and helpful suggestions.

GENERAL GEOLOGY.

The southwest section of the Coeur d'Alene District is an area of folded sedimentary rocks belonging to the Belt Series (Algonkian). The folds show a general east-west strike, and the axial planes tend to dip steeply to the south. The area is traversed from east to west by one of the major structural features of northern Idaho, the Osburn fault. Studies by Umpleby [3] have shown that the vertical displacement along the fault may vary from 1,000 to over 10,000 feet, and that the horizontal component of movement is nearly 12 miles. Detailed work by Umpleby and Hershey [4] indicates that the south block has moved west with respect to the north block. A number of minor faults south of the Osburn fault have been mapped and described in the literature. These appear to be subsidiary faults, related to the major displacement along the Osburn fault. Associated with these east-west fractures is a group of fissure veins, whose high silver content has given to the area the name "Silver Belt." The Sunshine vein is located on the north limb of the Big Creek anticline. Its

[3] Umpleby, J. B.: Jour. Geol., 32: 601–614, 1924.

[4] Hershey, O. H.: Min. and Sci. Press, 104: 825–827, 1912.

strike roughly parallels the axis of this fold, and it dips steeply to the south, paralleling the axial plane of the Big Creek anticline.

The country rock of the Sunshine Mine is the St. Regis formation, consisting of quartzitic and calcareous shales with thin interbedded bands of quartzite. In the immediate vicinity of the vein these shales have been bleached to a pale gray-green color. The Revett formation, which underlies the St. Regis, has been encountered in the lower levels of the mine.

Some movement has taken place along the Sunshine fissure, both before and after deposition of the ore. The total displacement is not believed to be very great. The vein walls are generally sharp and well-defined, and where post-mineral movement has occurred, thin seams of waxy sericitic gouge mark the vein-wall rock contact.

THE ORE.

The Sunshine ore is generally quite massive, containing many small cavities lined with minute crystals of siderite, quartz, and tetrahedrite. The important gangue minerals are siderite and quartz. The sulphides are pyrite, arsenopyrite, tetrahedrite, galena, bournonite, and chalcopyrite. Of these, pyrite and tetrahedrite are the most abundant. Arsenopyrite is common in the richer zones of the vein, where it is intimately associated with tetrahedrite. Galena, bournonite, and chalcopyrite are present only in minor amounts.

Surface or near-surface specimens of Sunshine ore were not available to the writer. Ransome,[5] in 1908, listed galena, tetrahedrite and proustite as the important minerals of the present Sunshine Mine, then called the Yankee Boy. Proustite has not been identified by the writer in any of the specimens from the lower levels, despite a careful search for silver minerals. Erythrite has been reported from the oxidized zone.[6]

Lindgren[7] classed most of the Coeur d'Alene ores as "mesothermal" in origin, placing them in a sub-group of this division

[5] Ransome, F. L.: U. S. Geol. Surv., Prof. Paper 62: 188, 1908.

[6] Shenon, P. J., and McConnel, R. H.: Idaho Bur. Mines and Geol. Pamph. 50: 8, 1939.

[7] Lindgren, W.: Mineral Deposits, 1933 Ed., p. 570.

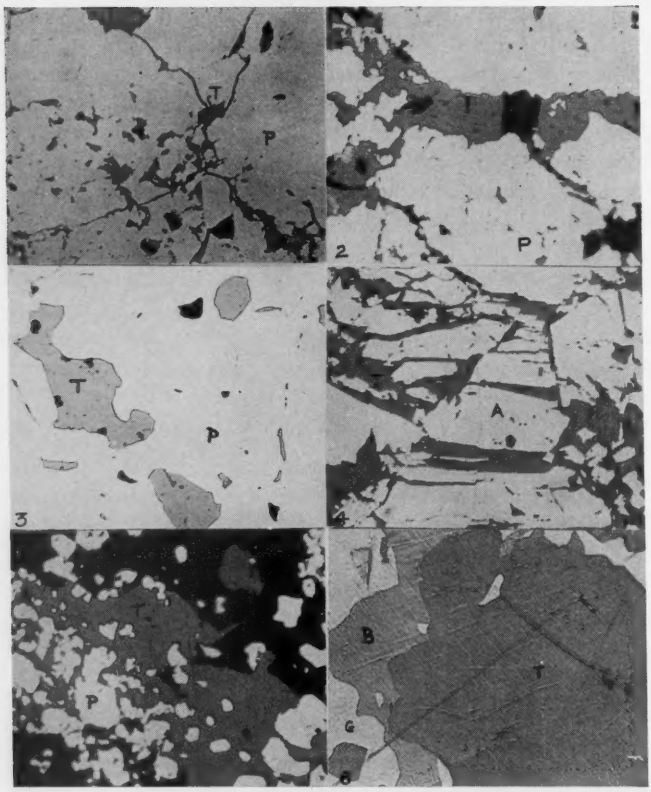


FIG. 1. Veinlets and blebs of tetrahedrite (T) in pyrite (P), many of which began along fractures in the pyrite and were enlarged by replacement. × 120.

FIG. 2. Pyrite (P), penetrated and partially replaced by larger veinlets of tetrahedrite (T), representing a more advanced stage of replacement than shown in Fig. 1. × 120.

FIG. 3. A portion of a large pyrite area (P) penetrated along minor fractures by blebs and veinlets of tetrahedrite (T). Replacement has developed straight contacts, which may represent boundaries of individual pyrite crystals. Black is gangue. × 120.

which he called "galena-siderite" veins, containing "little tetrahedrite and . . . poor in silver."[8] Lindgren placed the Wood River deposits in another sub-group, the "tetrahedrite-galena-siderite" type.[9] Of these two sub-groups, the Sunshine ore is probably more similar to the Wood River type, although the Sunshine ore does not contain the large quantities of galena and sphalerite present in the Wood River ores. While differing in some respects from the Coeur d'Alene and Wood River types, the Sunshine "tetrahedrite-siderite" ore is by no means unique. In hand specimen the Sunshine ore bears a close resemblance to a silver-lead ore from the central Transvaal, described by Wagner.[10] Some similarity between the silver-lead fissure veins of the Slocan District, British Columbia, and the Sunshine ore may be mentioned.

Together with the various Coeur d'Alene deposits, the metalliferous veins of the Silver Belt are believed to be genetically related to the northern end of the Idaho batholith.

Paragenesis.—Siderite appears to have been the earliest of the vein minerals and continued to be deposited during most of the mineralization period, even after virtually all of the metallic minerals had formed. The introduction of pyrite began during the early stages of siderite deposition and preceded quartz, which, like siderite, continued to form during most of the period of mineralization. Consequently, under the microscope both siderite and quartz are found to cut or replace the sulphides. The quartz is of the massive, coarsely crystalline variety referred to as "bull quartz."

[8] Ibid., p. 570.
[9] Ibid., p. 566.
[10] Wagner, P. A.: ECON. GEOL., 19: 651–667, 1924.

FIG. 4. Fractured arsenopyrite (A) penetrated by veinlets of tetrahedrite (T), with partial replacement of the arsenopyrite. × 120.

FIG. 5. Small crystal remnants of pyrite (P) in tetrahedrite (T). Black is gangue. × 120.

FIG. 6. Galena (G) replacing tetrahedrite (T) with the development of contact bournonite (B), which appears to be an intermediate reaction product in the replacement of tetrahedrite by galena. × 120.

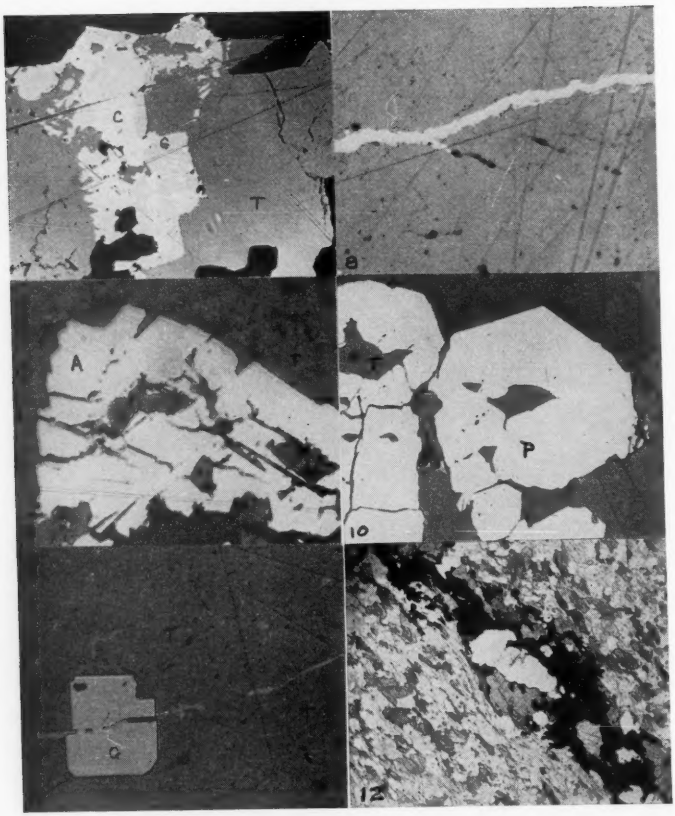


FIG. 7. Tetrahedrite (T) being replaced by galena (G) and chalcopyrite (C). Black is unreplaced siderite. × 120.

FIG. 8. Veinlet of chalcopyrite cutting tetrahedrite. × 120.

FIG. 9. A large crystal of arsenopyrite (A) partially replaced by tetrahedrite (T) and gangue (black). × 120.

FIG. 10. Pyrite crystals (P) apparently being centrifugally replaced by tetrahedrite (T). × 120.

FIG. 11. A crystal of galena (G) developed in tetrahedrite (T) and both minerals cut by a thin veinlet of chalcopyrite. × 120.

FIG. 12. Thin section of a veinlet composed of siderite, quartz, and

The exact relations between pyrite and arsenopyrite could not be determined because the two minerals were not observed in contact with each other. Arsenopyrite, however, is definitely cut by veinlets of tetrahedrite, proving its earlier age (Figs. 4, 9). The normal relation between pyrite and arsenopyrite, as observed in similar deposits elsewhere, would place pyrite as the earlier mineral.[11]

The introduction of tetrahedrite, following pyrite and arsenopyrite (Figs. 1–5), represents the most important phase of metallization. Although the pure tetrahedrite commonly contains sufficient silver to be classed as "freibergite," the silver content of the tetrahedrite varies throughout the mine, and it may be termed simply "argentiferous" tetrahedrite. Examination of numerous polished surfaces revealed no silver minerals in the tetrahedrite. It is thus assumed that the silver is present as an isomorphous constituent in the tetrahedrite. Quartz is an abundant gangue mineral associated with the tetrahedrite areas.

At widely spaced intervals in the ore body a separate vein with an average width of about one foot, containing chiefly galena, cuts the main tetrahedrite vein. Elsewhere, the galena vein, if present, is separated from the main tetrahedrite vein by two to ten feet of wall rock, on the hanging wall side. The field evidence indicates that the galena is later than the main tetrahedrite mineralization. Microscopic examination of material from the main vein, where it is cut by the galena vein, shows galena replacing tetrahedrite (Fig. 7). Numerous partially replaced remnants of tetrahedrite occur near the walls of the cross-cutting galena veinlets. In some instances bournonite, the copper lead-antimony sulphide, has developed along the contact between galena and tetrahedrite (Fig. 6). The bournonite is probably a reaction product representing an intermediate stage in the replacement of tetrahedrite by galena, since it is found only in such relation.

[11] Guild, F. N.: Econ. Geol., 12: 297–353, esp. p. 300, 1917.

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sulphides in bleached wall rock, parallel to the grain of the country rock, (calcareous phyllite). Siderite (high relief) also occurs in the country rock. ×25.

Massive argentiferous galena, taken from places where the galena vein is completely separated from the main tetrahedrite vein, shows minute blebs of tetrahedrite included in the galena. The tetrahedrite occurring in this manner appears to be due to unmixing from a solid solution in galena. The tetrahedrite may have been derived from unexposed intersections of the galena vein with the larger fissure. The silver content of the galena is believed to be due to included tetrahedrite, the minute blebs of which were often not revealed until the galena was etched with nitric acid.

Chalcopyrite is present only as a minor constituent and has been found in those areas where the galena vein has cut the main tetrahedrite vein. It occurs as minute veinlets penetrating tetrahedrite and galena (Figs. 8–11). This represents the final stage of metallic mineralization.

POST-MINERAL MOVEMENT.

Post-mineral movement in the Sunshine ore-body is shown by the development of shearing in galena stringers, by cross-faulting of the main vein, and by the thin seams of sericitic gouge along the vein-wall rock contacts. Specimens of sheared galena from the Sunshine mine show fragments of wall rock and gangue surrounded by the sulphide vein matter. These fragments appear to have been caught up during the same post-mineral movement responsible for the shearing of the galena. Sheared galena similar to that of the Sunshine mine has been found elsewhere in the Coeur d'Alene district, namely at the East Hecla mine and the Interstate Callahan mine. Waldschmidt, writing of sheared galena from the East Hecla mine, states that "deformation by pressure causes a flow structure in which the galena acts as a plastic mass, containing fragments, frequently rolled and transported, of the harder minerals."[12]

A gneissic galena common in the Slocan District, British Columbia, resembles the Sunshine material in many ways. Uglow gives a description of the sheared galena, which might well have

[12] Waldschmidt, W. A.: Econ. Geol., 20: 573, 1925.

been written of the Sunshine material. ". . . The crystal grains of galena are developed in parallel orientation, and this parallelism is very well brought out by the cubic cleavage of the galena. Cleavage faces are usually curved, suggesting that they have been formed after deposition, or that they developed under conditions of deforming stresses." [13] In a later paper on the Slocan deposits, Bateman warns against misinterpretation of the evidence in galena which has undergone flowage and recrystallization. ". . . the numerous inclusions of wall rock inclosed by galena may not be replacement residuals as they appear to be, but fragments incorporated during rearrangement of the galena." [14]

The main Sunshine vein is offset at irregular intervals by steeply dipping cross faults. Displacement rarely exceeds the width of the vein. The surfaces of the fault planes are slickensided and covered with a thin black gouge. These minor faults are thought to be related to regional structural adjustments following the mineralization epoch.

UNIVERSITY OF MINNESOTA,
MINNEAPOLIS, MINN.,
Feb. 6, 1940.

[13] Uglow, W. L.: ECON. GEOL., 12: 648, 1917.
[14] Bateman, A. M.: ECON. GEOL., 20: 562, 1925.

DISCUSSION AND COMMUNICATIONS

ADDITIONAL AIDS IN ILLUSTRATION.

Sir:—Recently-described methods for expediting and simplifying the making of technical illustrations [1] have left unsolved several of the most troublesome patterning problems. Practical solutions for some of these will be briefly outlined.

"True random" stipple patterns can be produced by the carbon transfer process by the use of sandpaper as a master pattern. To apply, place a sheet of sandpaper on the drawing board, abrasive side up. Over it place a sheet of carbon paper, carboned side up. Atop this, face down, place the drawing. With a suitable tool, rub the back of the drawing in those areas where a transferred pattern is desired. A typical "sandpaper screen" pattern is shown in Fig. 1.

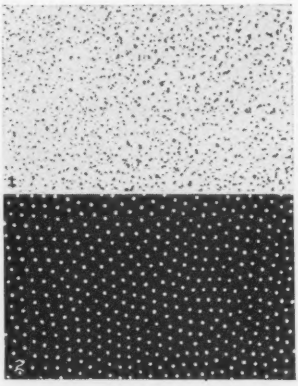
The arrangement and spacing of the pattern elements is determined by the grade of sandpaper used as the master pattern. The size of the elements may be varied by using various rubbing tools, or by interposing sheets of paper between the master pattern and the carbon paper.

Negative Ben Day, which produces a white pattern on a black field, usually consists of a transparent base sheet on which the pattern is printed in white ink. The black field over which this is applied must usually be painted onto the drawing. The time necessary for the drying of the black paint makes the use of standard negative Ben Day inconvenient. Special negative Ben Day, which may be applied quickly and handled within a minute of its

[1] Ridgway, J. L.: Scientific Illustration, Stanford Univ. Press. 1938. Ives, R. L.: Fabricated diagrams, Journal of Geology, Vol. XLVII, pp. 517–545, 1939. Thornthwaite, C. W., and Stuart-Sharpe, C. F.: Patterns on maps and drawings by the carbon transfer process, Science, 91: No. 2623, pp. 367–368, 1940.

application, may be produced in quantity at low cost by photographic means.

Attach a piece of standard positive Ben Day of the pattern desired to a piece of glass. Using this as a negative, print from



FIGS. 1 AND 2.

it, on " hard " photographic paper, as many copies as are desired. If " same size " negative Ben Day is desired, the printing is most conveniently done by contact. If any other size is desired, it can be printed by projection. Typical negative Ben Day produced in this manner is shown in Fig. 2.

To apply nontransparent Ben Day (either positive or negative), trace the outline of the area to be patterned on any convenient semitransparent substance, such as cheap typewriter paper, tracing paper, or tracing cloth. Using a temporary cement, such as " frisket," attach the tracing to the pattern sheet. Trim both pattern sheet and tracing to the desired outline. Cement the pattern in place, then strip off the tracing and remove the excess cement. At times, when especially neat work is desired, it is necessary to blacken the edge of the Ben Day with India ink.

Use of the " sandpaper screen " and nontransparent negative

Ben Day is especially convenient on drawings that are to be reproduced by planography and related processes.

RONALD L. IVES.

UNIVERSITY OF COLORADO,
BOULDER, COLO.,
May 21, 1940.

THE COAL RESERVES OF CANADA.

Sir: The writer is not a geologist but a mine operator and, as such, has had an opportunity to put to the test statements of geologists in regard, particularly, to the coal reserves of Canada.

In 1913 the International Geological Congress announced 7,397 billion tons of coal in reserve in the world. Of this total United States led with 3,838 billion tons while Canada followed with 1,234 billion tons. Canada, therefore, with one-sixth the coal reserve of the world, is second only to the United States. These are household words in Canada. It will be shown that this estimate, insofar as Canada is concerned, is an absurd exaggeration, has been known to be such for many years, has done great harm, and that such attempts as have been made by Canadian geologists to put things right have, so far, been successfully blocked.

In 1920 the writer was assigned as resident manager at a Vancouver Island colliery. Congress figures prepared by Canadian geologists, showed a reserve in the Island of 5,793 million tons. This is good coal and as it is almost the only tidewater coal on the American Pacific an important industry was visualized. He had not been there long when he found that the neighboring coal companies were drilling in areas stated to contain coal and they were not finding coal. Not only was this common, but structural weaknesses and excessive gas prevented the commercial working of coal below 2,000 feet in depth as well as much of the coal above that level. He reported the matter to Ottawa and J. D. MacKenzie, in charge of the Vancouver office of the Geological Survey of Canada, was sent to check up. He spent two seasons on the work and on the basis of available coal, cut the total to 26 million tons and said: " It is necessary in the interests of national economy that

the amount of coal available for present and future use be ascertained with some precision."

In 1925 Alberta, to which the Congress has allotted 1,075 billion tons, or 14 per cent of the world's total, decided to check up. The work was done by Dr. J. A. Allan, head of the Department of Geology of the University of Alberta. He cut the reserve (Evans Report, 1925) to 28 billion tons and later (Barlow Report, 1935) to 20 billion tons. Among the casualties was practically the entire block of 669 million tons of anthracite coal, stated to be "actual."

These disclosures, and their accuracy has never been questioned, simply cut the foundation from under the entire estimate as far as Canada is concerned and cast grave doubt on the figures for other parts of the world. Yet those in control, rather than be frank with the public, have offered such excuses as: "There is still so much coal that the matter is of no practical significance." This is not only a camouflaged admission of error but, as a statement of fact, is quite untrue. If MacKenzie and Allan are wrong they should be shown to be wrong; if right then, not only in justice to them but for the sake of a worth-while country, their figures and the serious situation they indicate should be recognized.

That, however, is not the way things have been done. The Canada Year Book, the outstanding official publication, has ignored the work of MacKenzie and Allan and quotes the Congress reserve as "sufficient for an unthinkably long period." Allan's work is actually ignored by the Government of Alberta that employed him. In 1931 McGill University published a "Symposium" on coal in which Congress figures were quoted but all reference to the MacKenzie and Allan figures was omitted. Stephen Leacock, formerly head of the Department of Economics at this university, has, based on Congress figures, thrilled Canadians with the story that they have coal for 36,000 years—the "unthinkably long period" referred to above. This statement was the basis for a discussion on coal in the House of Commons at Ottawa last year. With few exceptions mining organizations

in Canada either refuse to print criticism of Congress figures or close a discussion when vital facts are likely to be disclosed.

Probably the strangest situation of all is that which exists in British Columbia. Recently the MacDonald Commission was appointed by the Government of this province to investigate the coal problem. This was a judicial commission but it refused to consider the evidence of MacKenzie, backed by the up-to-date evidence of the coal companies, and, basing its conclusions on the Congress figures backed by McGill, reported the province to be "blest with a richness of supply that passes the estimation of man." Yet today there is ghost camp after ghost camp throughout this field and men thrown out of work contemplate the statement of the Commission that there are hundreds of millions of tons of coal in reserve in areas where the operating companies have stated that the coal is worked out and have abandoned the mines. The Vancouver Island field, which should be an important field for centuries, is now a minor operation and its end appears to be only a few years distant.

It is time, therefore, to wake up not only from the dream of coal "illimitable in quantity and incomparable in quality" which is at the back of Canada's wasteful development, but also from the dream that there is even ample coal. Reference has been made to the lack of anthracite in a country where the southern boundary averages only 40° above zero. We have no cannel coal. Reference has also been made to the shortage in Vancouver Island, Canada's third most important field. Even the 20 billions in Alberta is handicapped by the fact that it is half lignite and subbituminous and the remaining bituminous coal has physical properties that bar it, except in limited quantities, from the outside market. There is only low-grade lignite in Saskatchewan and Manitoba; no commercial coal or no coal at all in Ontario or Quebec, the home of two-thirds of Canada's population; and the coal in the Maritime Provinces is high cost coal mined far out under the sea and, like Alberta coal, has to be backed by a heavy subvention in order that it may compete in the Ontario market

with American coal. Notwithstanding this subvention Canada still imports half her coal. All this, certainly, does not indicate an ample reserve.

It should be remembered that Canadian borrowings and spendings are based on the stories that our natural wealth is so vast that we can afford extravagance and waste. This coal estimate is one of the chief supports of that absurd idea. These stories are not "optimistic" stories; they come in the class referred to by Jeremiah as "false dreams and lies," and they wreck modern countries just as they wrecked Judah in Jeremiah's time.

In considering this matter two misconceptions stand out above everything else. The first is that Carboniferous regularity has been attributed to Cretaceous seams. This was definitely the case in regard to Alberta and British Columbia. This is a Canadian error and it was pointed out by Allan in no uncertain terms. It shows that the Canadian geologists who made the original estimate did not realize it.

The second major error concerns geologists as a whole. They appear to have improper understanding as to what constitutes a reserve and the rest of the world, taught to believe that a reserve means money in the bank or, essentially, something available on demand, has been seriously misled. The geologist's idea of a reserve, and in this case it is not only the Canadian geologist's idea but that of the Congress as a whole, that seams over 1-ft. thick to 4000-ft. depth and seams over 2-ft. thick between 4000-ft. and 6000-ft. should be included in the reserves, without first demonstrating that they exist to and can be mined to those depths, is among the chief absurdities of the engineering world. Another uncalled for error was made when "actual" and "probable" tonnages were added together and the total called a reserve. An American geologist once came to Canada and gave an address on the age of the world. "What," he said, "are a few million years among friends." The same idea appears to govern too many geologists when estimating reserves. "What," they apparently say, "are a few billion tons among friends."

It is true that it is due to such geologists as MacKenzie and Allan, with a proper understanding of what constitutes a reserve,

that these errors have been pointed out, but these men have had no backing whatever either in Canada or elsewhere from geologists or, I regret to say, from mining engineers or government mining departments. They have been allowed to remain under a cloud and their painstaking and vitally important work ignored.

If geologists wish to retain the confidence of the public they must realize that the well defined rules governing the estimation of reserves apply to geologists as well as to others; they should promptly withdraw this farcical estimate and replace it with something dependable.

C. M. CAMPBELL.

VANCOUVER, B. C.,
May 16, 1940.

REVIEWS

The Geology and Mineral Resources of the Neighbourhood of Raub, Pahang, Federated Malay States, with an Account of the Geology of the Raub Australian Gold Mine. By J. A. RICHARDSON. Pp. ix + 166; figs. 34; pls. 5; geol. map. Geol. Surv. Dept., Federated Malay States. Price, $3.00 (Straits).

This is the third of a series of memoirs descriptive of the geology and mineral deposits of areas covered by topographical sheets on the scale of one inch to the mile of the Federated Malay States. The two previous memoirs dealt with parts of Perak, and the present memoir describes part of the State of Pahang (sheet 3 B/4) in which is situated the most important gold mine in Malaya, namely the Raub Australian Gold Mine.

The author is a recent recruit to the Geological Department of the Federated Malay States, and his first report is an important contribution to the study of both the geology and petrology of Malaya and of its mineral resources.

The area lies in the State of Pahang immediately east of the Main Range, the granitic backbone of Malaya. The strata are arranged in crude strips parallel to this axis, that is from N.N.W. to S.S.E., the eastern edge of the Main Range occupying the western edge of the sheet mapped, and the western edge of another granitic intrusion, that of the Gunong Benom Range, lies on the eastern edge of the sheet.

The principal stratified geological formations are grouped as the Arenaceous (Triassic) and the Calcareous (Permocarboniferous) formations. Into these are intruded the granitic and allied rocks (granite- and quartz-porphyries) of the Main Range on the west and of the Gunong Benom Range on the east, thought to be of post-Triassic age. There are also, in the eastern foothills of the Main Range, intrusive serpentinous rocks regarded as post-Triassic but pre-granitic in age; and in the western foothills of the Gunong Benom Range there are non-serpentinized ultra-basic and basic rocks that have been hybridized by the Gunong Benom granite, and must, therefore, be regarded in their hybrid forms as post-granitic in age, and not as pre-granitic as stated in the legend of the map, although the original ultra-basic and basic rocks are demonstrably pre-granitic.

The sediments of both the Arenaceous and the Calcareous formations

have suffered extensive metamorphism in places, and in one place, curiously enough in proximity to the serpentines, there are important amphibole-schists, thought now to be the products of the metamorphism of the calcareous rocks. The region has been subjected to compressive forces from the W.S.W. and E.N.E., that is at right angles to the Main Range axis, both prior to and after the introduction of the intrusive granites. As a result, the sedimentary formations occupy a broad belt, between the granitic intrusions, folded into anticlines, synclines, and isoclines, with the axial planes dipping towards the E.N.E. The Main Range granitic intrusion was accompanied by tin mineralization as well as by a later hydrothermal gold phase, the distribution of which was controlled by structural features connected with the folding, especially the various fault-systems.

In his discussion of the geological relationships the author adopts the customary view that the arenaceous rocks are Triassic in age and the calcareous rocks Permocarboniferous. The evidence for such a comprehensive attribution of outcrops according to lithology is, however, not strong, and we must expect future research to lead to a less simple solution. The author himself does not seem convinced even as to the correct sequence of the arenaceous and calcareous formations, but he draws his sections (Fig. 15) to conform with the hypothesis adopted. It would be quite easy to give an opposite interpretation. However, the Malayan geologists have done the best that is possible at present, in view of the paucity of fossil evidence.

Concerning the origin of the amphibole-schists the author records the variation of previous opinion, in accordance with which these rocks have been alternately regarded as metamorphosed dolerites and metamorphosed calcareous rocks, and finally adopts the latter view, on the basis of both petrographical and chemical analyses. He throws doubt, however, on this solution, presumably unintentionally, by calculating the norms of the amphibole-schists, overlooking the fact that the quantitative classification applies only to igneous rocks. These norms show from 44 to 57 per cent of feldspars, from 37 to 52 per cent of pyroxenes plus olivine, and from 3 to 12 per cent of iron-ores.

To the petrographer the most interesting and important part of this memoir will be Mr. Richardson's study of the hybrid rocks on the western flank of the granitic intrusion constituting the Gunong Benom Range. The existence of these rocks has been known for some years, and they were described by Mr. E. S. Willbourn in 1938 as ranging from biotite-hornblende-granite through biotite-syenite and pyroxene-bearing varieties to pyroxenite. Mr. Willbourn also expressed the opinion that many of these rocks are hybrids. Mr. Richardson is careful to mention that the geological survey of which this memoir is the record had as its primary

object the investigation of the mineral resources of the area, and that as no valuable deposits are known to occur in the Gunong Benom foothills it has not been possible to devote sufficient time to enable a fully authoritative theory regarding these hybrid rocks to be developed. Nevertheless, he gives a provisional hypothesis of the petrogenesis of this complex suite, reinforced by chemical analyses made by the chemists of the Department, Messrs. G. M. Harral and W. A. Tooke. For the descriptions and discussions on this work reference must be made to the memoir; but, briefly, the author's hypothesis is that perknites, pyroxenites, and hornblendites of pre-granitic age have been invaded by feldspar-rich rock, generally granitic magma, of the Gunong Benom Range, with the formation of hybrid biotite-hornblende-granite as an end product, and the production also of hybrid biotite-hornblende-monzonite, and hybrid adamellite, as other end products. He considers that pyroxenite, or an even more ultrabasic rock was one of the parents of the hybrid suite; and, making certain assumptions, he calculates the composition of the hypothetical parent, which corresponds with pyroxene-peridotite. The result was also complicated by contamination with sedimentary material into which first the ultrabasic and basic magmas were intrusive, and later the granitic magma.

Mr. Richardson points out that the Cheroh serpentine of the Main Range foothills, which he considers was derived from pyroxenite, saxonite, and peridotite, shows no signs of granitization, although its position is comparable with that of the hybrid suite. There appears to the reviewer to be another reason why the serpentines of the Main Range and the ultrabasic parents of the Gunong Benom hybrids should not be equated. Although the Cheroh serpentine contains nickel and chromium, the latter present as chromite and picotite, these elements are not recorded as present in the Gunong Benom hybrids. Further, although the heavy mineral assemblages from the superficial deposits derived from the serpentines include chromite and picotite, those derived from the hybrid suite do not. The existence of the hybrids makes it certain that the ultrabasic parents thereof are pre-granitic in age. The absence of granitization of the Cheroh serpentine, and the absence of intrusive contacts of the Main Range granite towards the serpentine, on the other hand, makes their relative age uncertain, although the author regards the prevalence of shearing in the serpentine, and the known association of dynamic alteration with the period of intrusion of the Main Range granite as reasonably conclusive evidence that the serpentine is pre-granitic.

Although the main purpose of Mr. Richardson's survey was economic yet somewhat over half his memoir is devoted to the general geological and petrographical aspects, which form a necessary introduction to the discussion of minerals of economic interest found in the area, to which we may now turn.

The minerals of economic interest are gold, cassiterite, cinnabar, scheelite, monazite, zircon, ilmenite, and chromite, and some nickeliferous serpentine, of which only gold and tin are known to be present in economically important quantities.

Excluding the small amounts of chromite and nickel in serpentine, all these minerals owe their presence to the intrusion of the granite of the Main Range. Consequently, its history is of the greatest interest and importance to the student of Malayan ore deposits. This history is analyzed (p. 38) by the author as including 8 stages, which may be summarized as follows:

Stages 1 (earliest) to 3. Introduction of the granitic magma, with uplift of sediments, differentiation of the magma, with marginal assimilation of sediment in many localities, followed by cooling of the magma and thermal metamorphism of the sediments, enhanced by the action of siliceous effluents from the granite.

Stage 4. *Tin mineralization* in the granite as veins of cassiterite, generally accompanied by quartz and tourmaline, and less commonly by topaz; disseminations also formed. Mineralization most pronounced at the periphery of the batholith.

Stage 5. Widespread fissuring of the surrounding sediments and in the igneous rocks.

Stage 6. Late stage differentiates of the magma, including aplite,[1] granophyre, pegmatite, granite- and quartz-porphyry, and quartz veins, intrusive both into the batholith and into the sediments.

Stage 7. *Gold mineralization*, effected by deposition from hydrothermal solutions, with in addition the deposition of quartz, pyrite, pyrrhotite, arsenopyrite, stibnite, scheelite, and traces of chalcopyrite and cerussite. It generally followed fault-zones in fissile shale of the calcareous series, but less commonly occurred in quartz-mica rock, and also in granite. Calcite and dolomite, leached from the country, and scheelite, formed by the reaction of limestone with tungstic oxide, were deposited at this time in some of the auriferous lodes at the Raub mine.

Stage 8 (latest). Post-mineralization faulting, generally N.N.E. to N.E. in direction, but less commonly in other directions.

The earlier formed of the two valuable minerals, namely cassiterite, although by far the most important mineral produced in Malaya, is of subordinate value in this area to gold. It will, however, be discussed first.

The production of cassiterite concentrates from Ulu Pahang, which includes the Raub district, has ranged annually from only 283 tons (1934) to 1,613 tons (1923) since 1903. The tin-ore occurs partly in low-grade alluvium of the valley flats, but mainly in the hills in the form of alluvial and eluvial deposits, as well as in low-grade disseminations *in situ e.g.* in pegmatite and greisen. Most of the past production was obtained from the hills, mainly by ground-sluicing, and although the deposits so worked

[1] An unsuitable use of the term, which the author inherits from his predecessors, as the rock referred to is a muscovite-quartz-rock, whereas feldspars should be prominently present in a true aplite.

were generally small, yet some were very rich. Owing to the silting of rivers caused by this method of mining, disposal of tailings into rivers is at present prohibited, but the chief hope for the development of the tin-mining industry in this tract must depend on hydraulicing and ground-sluicing, with such safeguards as are possible, in the valleys and on the hillslopes, followed by working low-grade disseminations *in situ* that may be uncovered as a result of such work. There seem to be no areas suitable for large-scale dredging, but there are possibilities of employing a small dredge in certain valleys.

The most important mineral in this tract is gold, for which this part of Malaya has long been famous: for both gold and tin were produced in Malaya prior to the conquest of Malacca by the Portuguese in 1511, the gold causing the country to be known as the *Aurea Chersonesa*, or the Golden Chersonese.

Although the gold deposits of Malaya occur in a belt of country east of the Main Range stretching from the southern border of Siam in the north through Kelantan State and Raub in Pahang to Malacca in the south, a total distance of about 200 miles, the only important deposits yet discovered are at Raub. These are worked by the Raub Australian Gold Mining Company, Limited, floated in 1889. This mine or rather group of mines had produced up to the end of 1938 a total of 672,097 ounces troy, the production for 1938 being 29,789 ozs.

In his recent "Report upon the Mining Industry of Malaya" (Kuala Lumpur, 1939) the reviewer has noted the imperfections of Malayan mineral statistics and has collected therein 40 years' data of production of all minerals in Malaya, in an attempt to rectify these deficiencies, the sources used being partly official and partly data provided by mining companies. Mr. Richardson in his memoir gives a table (No. 14) of production of gold from 1889, both for the State of Pahang as a whole, and for the Raub mine separately. His figures for Pahang agree with the reviewer's in 21 years and differ in 17 years. As in the latter cases Mr. Richardson's figures are usually the larger, one would be inclined to accept them as the more comprehensive. Unfortunately, however, he gives in a later table (No. 17) details of the production of the Raub mine as shown in the Company's annual reports. For in this second table the totals for every year from 1902 onwards disagree with those for the Raub mine in Table 14. The confusion is helped by an extraneous figure of 18,658 tons against the year 1901, which has moved upwards by one year all the higher figures in the same column. Rectification of these figures, which then mainly agree with those in Table 14, does not remove the discrepancies for the years below the error, which all disagree with those in Table 14. This point is mentioned both as illustrating the difficulties of Malayan mineral statistics, and to prevent Mr. Richardson's

figures being quoted by students of mineral statistics, except with discretion.

The gold deposits occur in an area of folded, fissile, calcareous shale of the Permocarboniferous series, which strikes northwesterly and dips 70° easterly. There are four main systems of faulting, of which one system of compression faults coincides closely with the axial planes of the folding, and with the bedding planes of the shale. Mineralization has occurred along three different lines, two of them being the eastern and the western lode-channels located in zones of compressional folding: the third lies between these and is a zone of tensional faulting.

The minerals associated with the gold are quartz, calcite, sulphides, and scheelite. The order of deposition of these minerals is quartz; sulphides with gold; calcite, quartz, and scheelite; quartz. The gold is irregularly distributed, deposits of economic value in the lode-channels being confined to shoots. Later pressures, operating in a direction at right angles to the compressional folding, have caused areal down-tilting generally towards the northwest or north, with the resultant imposition upon many of the pre-existing structures of a general northerly pitch. Whether an influence has thereby been exerted upon the location of ore-shoots cannot be determined, owing to failure to maintain an assay plan. The mining company, by this omission, have thereby deprived themselves of possible powerful help from the geologist in their search for further ore-shoots.

Of the principal three lines of deposition the most important has proved to be the eastern lode channel, which has been mined for a distance of 14,000 feet along the strike in a succession of mines separated by cross-faults. A depth of 1,100 feet from the surface has been reached in Bukit Koman North. In a series of cross-sections the author illustrates the structures along this lode channel. The western lode channel has hitherto been mined only to shallow depths. The lode channels are commonly from 4 to 7 feet in width, but may be as wide as 70 feet, as on Bukit Koman level 5. The foot and hanging walls are demarcated by compressional fault planes with a polished veneer of graphite, and are commonly striated.

The lodes themselves consist of varying proportions of white quartz and black shale with subordinate calcite, with sulphides rarely in excess of 5 per cent of the ore.

At Raub Hole the ore occurs in quartz stringers in tension fissures at about 80° to the strike of the bedding planes of the shales. These stringers occur between two strike faults 170 feet apart, and themselves range in width from one-tenth of an inch to a maximum of 3 inches, with an average width of three-quarters of an inch. It is only the phenomenal richness of the stringers (values of several hundred pennyweights per ton are usual) that enables them to be worked, for a stope 4 to 5 feet wide

may be opened on one stringer one inch or less in width. As an example Stope No. 2 is cited, where an average width of 40 feet, with perhaps a total of 15 inches of auriferous quartz, is mined profitably to yield ore after handpicking averaging 5 dwts. of gold per ton. Scheelite and stibnite are abundant at Raub Hole.

The average grade of ore milled from some sections of the Raub mines can be judged from Table 20 of Mr. Richardson's report. This shows, in the case of the Bukit Koman Mine a tenor increasing from 3.7 dwts. in the period 1905 to 1909, to 18.7 dwts. in 1930–1934. This increasing tenor, according to the author, is partly due to selective mining and partly to an intrinsic increase in the tenor of the ore-bodies at greater depth. This is illustrated in a longitudinal section (Fig. 34).

To the management of the Company, Chapter XX of this work should prove the most useful, as therein the author discusses the geological possibilities of future development and discoveries at Raub. Taking into account the systems of faulting with both horizontal and vertical movement, the effects of pitch, the extension of existing ore-zones, and the possibility of a deeper one, Mr. Richardson makes several suggestions that if acted on may be fruitful of results, and it is evident that the future may still have much in store for Raub.

The author discusses also other occurrences of gold in this area, and it seems that there are in the Tersang valley, to the north of Raub, payable tracts of auriferous alluvium.

The excellent geological map on the scale of an inch to the mile is uniform in color scheme and symbols with the two preceding sheet memoirs. Knowing from personal observation the density of the Malayan vegetation, the reviewer must take this opportunity of expressing admiration first of the work of the Survey Department of the F.M.S. in producing topographical maps on this scale with 50 foot contours, and secondly of the geologists in being able to lay down the geological boundaries thereon, when tropical vegetation and weathering obscure so much. In this particular map Mr. Richardson has incorporated work done by Mr. E. S. Willbourn, the present Director of the Geological Survey Department, and has also had the advantage of being able to use Mr. Willbourn's notes. The pioneer work on this ground was, of course, done by Mr. J. B. Scrivenor, the founder of the Department.

In closing this review I should like to compliment the author on a scholarly piece of work that in its thoroughness both on the scientific and the economic side will be of much interest and use, both to the scientist and to the practical mining man.

L. L. FERMOR.

DURDHAM PARK,
BRISTOL, ENGLAND.
June 5, 1940.

The Geology of China. By J. S. Lee. Pages 528. Illus. 93. Thos. Murby & Co., London. 1939. Price, 30 s. Nordemann Pub. Co., Inc., New York. Price, $9.00.

This long awaited volume should be welcomed by all students interested in the geology of China because it is packed with information that heretofore has been difficult of access to those who have not been in a position to consult the widely scattered literature dealing with the subject. The author approaches his presentation from the structural point of view. His discussion is divided into two parts of which the first deals with the physiography and tectonics of the country and the second with its stratigraphy.

In the first part there is a very condensed account of the 19 provinces into which China is divided, followed by a summary of the character of its ancient floor, the marine transgressions and epochs of tectonic movements, the post-paleozoic formations and movements, the structures in the several large provinces, a description of the great folded features, and of the great E.–W. tectonic zones and of the development of the important shear-forms, especially of Eastern Asia. The final chapter in this part of the book deals with theoretical suggestions as to the mechanics of the processes that have yielded the tectonic types and the causes of the rhythms of crustal oscillations, and a comparison of the structural forms met with in China with those of the Appalachian district of the United States and districts in Western Australia, in Europe, Southern Africa, and the Northern Cordilleran sections in Canada, Alaska, and elsewhere.

The second part of the volume deals with the Pleistocene climate of China and the regional stratigraphy of the country. China is so large and there have been, comparatively, so many areas that have not yet been geologically mapped that it is impossible to correlate the formations in different areas except in a very general way. The entire nation has, therefore, been divided into 53 separate areas and a generalized account is given of the stratigraphical development in each area. Each stratigraphic division in a given area is briefly described and a list of the leading fossils that have been found in it and identified is given. The author states that each of the formations must cover large stratigraphic units, otherwise there would be no possibility of general correlation so long as large portions of the country remain unmapped. "Our present object," he says, "is to coordinate what is actually known from region to region in order to indicate what we need to know in the immediate future."

The job set for himself by the author is well done. His book is not easy reading because its style is so condensed. It is, however, packed with statements of facts well arranged and made easy of access by a good index. Moreover, a valuable "selected bibliography" is appended to each chapter and a short list of the titles of general articles. The volume thus has been

made an excellent reference book to the literature on the geology of China, so far as it is now known, and a dictionary of Chinese geological names. It is comprehensive and apparently accurate in its statements. It is unquestionably a necessity to all students of S.E. Asiatic geology.

W. S. BAYLEY.

Kemp's Handbook of Rocks, 6th Edit. By F. F. Grout. Pp. 300; Figs. 96. D. Van Nostrand Co., New York, 1940. Price, $3.00.

This well-known handbook, for use without the petrographic microscope, underwent five editions by J. F. Kemp and now after a long lapse, reappears completely revised by Professor Grout. The former arrangement has been kept, and all chapters have been rewritten and brought up to date; some have been considerably extended, such as those on calculations and on the origin of rocks. Hydrothermal alteration is included and many new illustrations appear. The glossary of petrographic terms, to which former users were wont to turn, is missing and instead is a list of rock names not included in the index. The revised book should prove to be a useful text and reference but we doubt if today it will ever regain the place occupied by the earlier editions.

Soil Conservation. By H. H. BENNETT. Pp. 993; Figs. 358. McGraw-Hill Book Co., New York, 1939. Price, $6.00.

This is a pioneer work by a foremost authority on a subject that of late has attracted much attention from the geologist, the geographer and the agriculturist. The waste of productive soil by rain and wind became acute during recent droughts. This book deals with the subject, the rate of soil erosion, the causes, the results, and methods of prevention.

Part I deals with "The Problem in the United States;" "Erosion and Civilization;" results, processes, types and rates of erosion and run off; relation of climate, infiltration, and physical and chemical properties of soils to erosion; relation of erosion to crop yields and vegetative changes; sedimentation and mass wastage.

Part II relates to soil conservation, dealing with crops, forests, preventative methods, and a detailed discussion of the various geographic and physiographic regions.

The book is well written, there are many instructive illustrations, and the subject is covered comprehensively. It contains much of geologic interest, and it is clearly the outstanding volume on the new subject of soil conservation.

BOOKS RECEIVED.

DAVID GALLAGHER.

Subsurface Geology of the Chester Series in Illinois. L. E. WORKMAN. Subsurface Geology of the Iowa (Lower Mississippian) Series in Illinois. J. N. PAYNE. Pp. 27; figs. 6. Illinois Geol. Surv., Rpt. of Invest. 61. Urbana, 1940.

Ouro No Centro de Minas Gerais. L. J. DE MORAES AND O. BARBOSA. Pp. 186; many (unnumbered) diagrams, sketch maps, and sections; 21 photomicrographs. Brazil Div. de Fom. da Prod. Min., Bol. 38. Rio de Janeiro, 1939.

Annual Report of the Mining Industry of Idaho for 1939. A. CAMPBELL ET AL. Pp. 341; numerous (unnumbered) illustrations. *A compendium with a wealth of data; excellent.*

Yazoo County Mineral Resources. F. F. MELLEN AND T. E. MCCUTCHEON. Pp. 132; pls. 2; figs. 17. Mississippi State Geol. Surv., Bull. 39. University, 1940. *Non-metallics with test data; discovery of oil in Mississippi.*

Geologic Map of Georgia. Under supervision of G. W. STOSE AND R. W. SMITH. In color, 40″ × 43″, scale 1:500,000. Georgia Div. of Mines, Mining, and Geol., 1939. *A joint product with the U. S. Geol. Surv. Excellent state map.*

Canadian Mines Handbook—1940. Pp. 272. Northern Miner Press, Toronto. Price $1.00. *Compendium and statistics of Canadian mines, including 133 producing gold mines (25 new mills last year); 30 producers of other metals; 900 active companies in 1939; reviews of 5713 companies. A handy reference.*

Principles of Mineral Dressing. A. M. GAUDIN. Pp. 554; figs. 260. McGraw-Hill, New York, 1939. Price $5.00. *A complete text book of the theory and practice of the various stages involved in modern milling; also contains valuable information for geologists.*

Geology and Ground Water Resources of Texas County, Oklahoma. S. L. SCHOFF. Pp. 248; pls. 5; figs. 13. Oklahoma Geol. Surv., Bull. 59. Norman, 1939. (*Cooperative study with U. S. Geol. Surv.*)

Geophysical Abstracts 95. Oct. to Dec. 1938. W. AYVAZOGLOU. Pp. 71. U. S. Geol. Surv., Bull. 909-D. Washington, 1939. Price 15 cents. *Contains 177 abstracts.*

Geology and Coal Resources of the Minot Region, North Dakota. D. A. ANDREWS. Pp. 40; pls. 5; figs. 7. Geol. map in color, 34″ × 38″, scale 1:125,000. U. S. Geol. Surv., Bull. 906-B. Washington, 1939. Price 50 cents. *18,094,592,000 tons of lignite; region unfavorable for oil.*

Gravel and Sand Deposits of Eastern Maryland. N. H. DARTON. Pp. 42; pls. 10; figs. 10. U. S. Geol. Surv., Bull. 906-A. Washington, 1939. Price $1.25. *Maps in color, scale 1:62,500, show occurrence of sand and gravel from about 45 miles NE of Baltimore to about 20 miles S of Washington.*

Geology and Fuel Resources of the Southern Part of the Oklahoma Coal Field, Part 4., The Howe-Wilburton District, Latimer and Le Flore Counties. T. A. HENDRICKS. Pp. 45; pls. 8; figs. 6. Geol.

and structure map in color, 60″ × 19″, scale 1:63,360. U. S. Geol. Surv., Bull. 874-D. Washington, 1939. Price 70 cents. *Coal, gas, sand, gravel, and brick.*

Oil and Gas Map of Illinois. A. H. BELL AND G. V. COHEE. 48″ × 28″, scale 1:500,000. Illinois Geol. Surv., Aug. 1, 1939. *Base map with overprint in red showing producing and abandoned oil fields, pipe lines, pumps, etc., and the outlines of the coal areas.*

The Mineral Industry of Alaska in 1938. P. S. SMITH. Pp. 113; figs. 3; base map of Alaska, 23″ × 16″, scale 1:5,000,000, with overprint showing key to all maps and publications. U. S. Geol. Surv., Bull. 917-A. Washington, 1939. Price 35 cents. *Review of the mineral production.*

Microscopic Determination of the Ore Minerals. M. N. SHORT. Pp. 314; pls. 14; figs. 31. U. S. Geol. Surv., Bull. 914. Washington, 1940. Price $1.00. *The new edition of this well known book contains 110 more pages than the preceding edition. These embrace all the most up to date material on methods of mounting, polishing, etching, and testing. The determinative data have been revised to include the results of a vast number of added observations on minerals, and the microchemical section has been enhanced by a wealth of new data. An indispensable volume.*

Clay Investigations in the Southern States 1934–35. W. B. LANG ET AL. Pp. 346; pls. 8; figs. 27. U. S. Geol. Surv., Bull. 901. Washington, 1940. Price $1.00. *Deals mainly with the bleaching clays of S. C., Tex., Ky., Tenn., Ala., Miss., Ga., and Fla.*

Geology of the Alaska Railroad Region. S. R. CAPPS. Pp. 201; pls. 10; figs. 1. U. S. Geol. Surv., Bull. 907. Washington, 1940. Price $1.25. *Brings together in condensed form the present state of knowledge of the geology of the region about 140 miles by 450 miles through which the railroad runs from Seward to Fairbanks. Three geological maps in color, each 35″ × 39″, scale 1:250,000.*

Geological Report on the Norton Gold Belt. R. Tyndale-Biscoe. Pp. 10; 1 sketch map. Southern Rhodesia Geol. Surv., Short Report No. 31. Salisbury, 1940.

Annual Report Uganda Geol. Surv. for 1939. Pp. 38; black and white geological map of Uganda 26″ × 27″, scale 1:1,000,000. Entebbe, 1940. Price Shs.2/–. *Brief account of the 1939 work and geological features encountered.*

Report of the Geological Survey Department for the Year 1939, Federated Malay States. E. S. WILLBOURN. Pp. 52; 1 fig. Kuala Lumpur, 1940. Price 25 cts. or 7d. *Many interesting, brief, geological descriptions; production statistics.*

Lower Laflamme River Area, Abitibi District. P.-E. AUGER AND W. W. LONGLEY. Pp. 33; pls. 2; geol. map in color, 40″ × 27″, scale 1:63,360. Canada Bur. Mines, Geol. Div. Rpt. 2, Quebec, 1939.

Carbonizing Properties and Petrographic Composition of Pocahontas No. 3-Bed Coal from Buckeye No. 3 Mine, Wyoming County, W. Va. and of Pocahontas No. 4-Bed Coal from No. 4 Mine, Raleigh County, W. Va. A. C. FIELDNER ET AL. Pp. 64; figs. 44; tables 22. U. S. Bureau Mines, Tech. Paper 604. Washington, 1940. Price 15 cents.

SCIENTIFIC NOTES AND NEWS

THE NOMINATING COMMITTEE OF THE SOCIETY OF ECONOMIC GEOLOGISTS presents the following nominations for office. This list may be added to by the membership at large, in accord with Section 16 of the By-Laws, and any additional nominations received by the Secretary by October 1, 1940, will appear on the ballot:

President for 1942, W. J. Mead; First Vice-President for 1942, K. C. Heald; Councilors for 1941–1943, W. E. Pratt, D. G. Thompson, A. B. Yates; Regional Vice-Presidents for 1941, Ben Lightfoot for Africa, J. A. Dunn for Asia, H. J. C. Connolly for Australia, F. A. J. Blondel for Europe, Manuel Santillan for North America and Friedrich Ahlfeld for South America.

ERNEST E. FAIRBANKS, formerly with Celo Mines, has been appointed Associate mineralogist with the U. S. Bureau of Mines, Eastern Experiment Station, College Park, Maryland.

E. C. ECKEL, B. C. MONEYMAKER and R. A. LAURENCE, geologists of the Tennessee Valley Authority have moved the geologic division offices to Chattanooga from Knoxville, Tennessee.

G. C. BATEMAN, president of the Canadian Institute of Mining and Metallurgy, and of the Ontario Mining Association, has been appointed Metals Controller for the Dominion government at Ottawa, under the Minister of Munitions and Supply.

The 26th Annual Meeting of the AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS will be held at the Rice Hotel, Houston, Texas, April 2–4, 1941.

C. K. LEITH, professor of geology at the University of Wisconsin, has been named by E. R. Stettinius, Jr., to aid in coordinating the flow of industrial raw materials from mines to factories for the recently appointed National Defense Committee.

S. H. DOLBEAR, R. L. HALLETT and H. K. MASTERS, all of New York City, have also been appointed as consultants to Mr. Stettinius as experts on chromium, tin, tungsten and antimony.

SCOTT TURNER was awarded an honorary Doctor of Science degree on June 12 by Kenyon College at Gambier, Ohio.

J. W. FURNESS, chief of the economics and statistics branch of the U. S. Bureau of Mines, has retired after eighteen years of service.

V. A. GILES has been made chief geologist for the Northern Pacific Railway Co.

P. D. WILSON, vice-president of Pardners Mines Corp. of New York, is in Preston, Oriente, Cuba.

E. T. HECK who has been on leave of absence has resumed his duties with the West Virginia Geological Survey.

E. F. TAYLOR is assistant geologist for the National Development Co. in the Philippines, working at present on the island of Cebu.

PHILIP WRIGHT has joined the mine staff of the San Mauricio Mining Co. in the Philippines.

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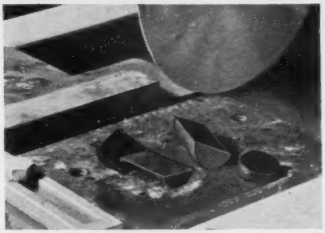

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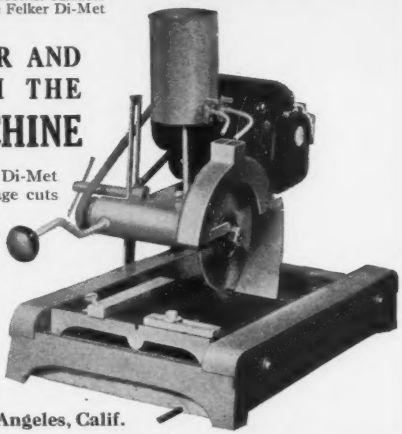

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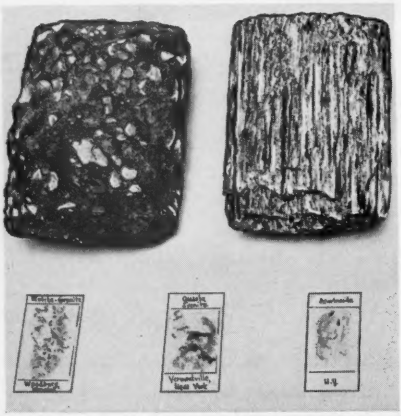

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